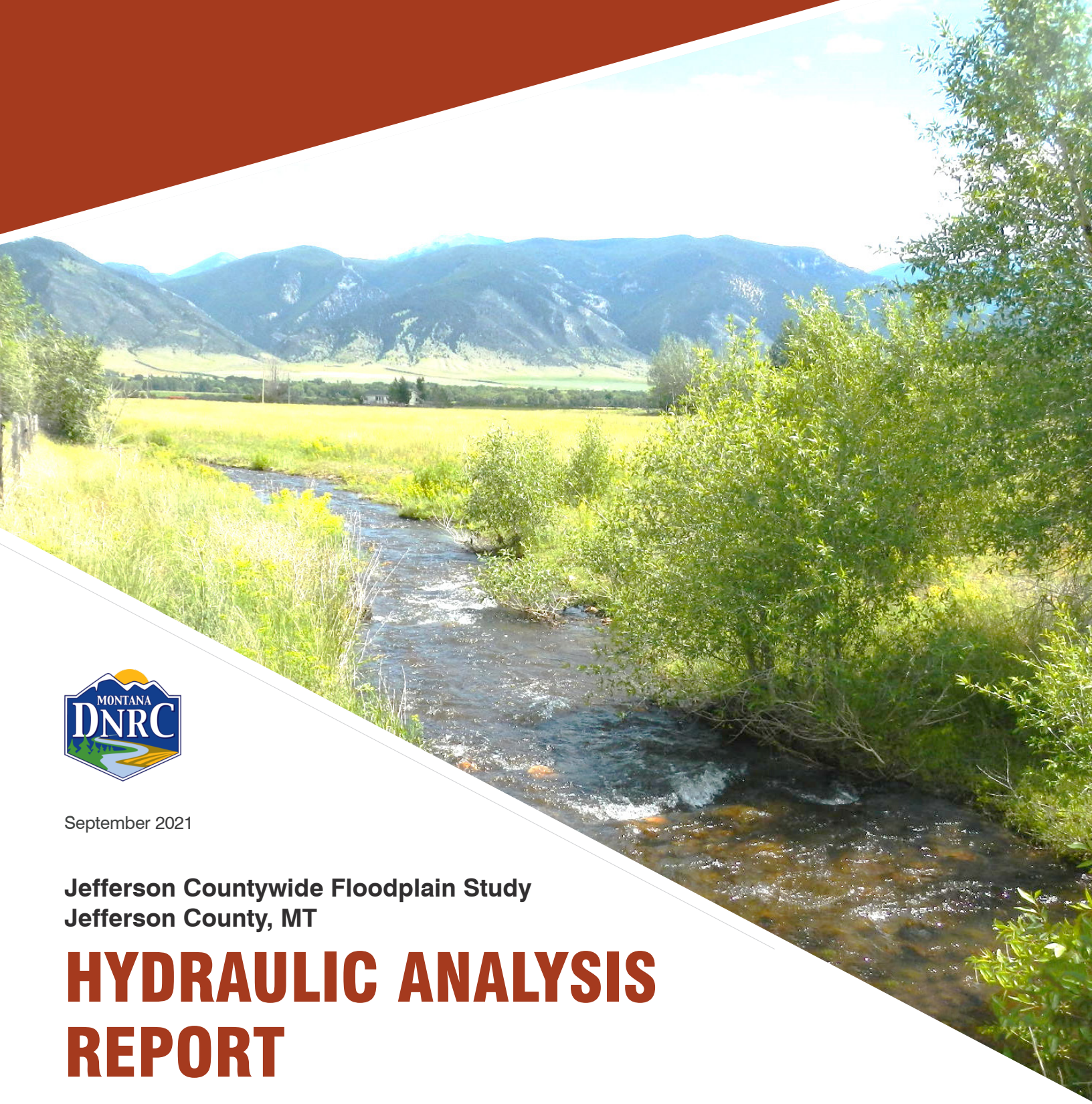

September 2021

Jefferson Countywide Floodplain Study
Jefferson County, MT

HYDRAULIC ANALYSIS REPORT

Prepared for:

Montana DNRC
Water Resources Division
1424 9th Avenue
Helena, MT 59620

Submitted by:

DOWL
222 North 32nd Street, Suite 700
Billings, MT 59101

Montana Department of Natural Resources and Conservation

Jefferson Countywide Floodplain Study
Jefferson County, MT

Hydraulic Analysis Report

June 2021

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1.0 INTRODUCTION

As part of a Mapping Activity Statement (MAS) contract initiated by the Montana Department of Natural Resources and Conservation (DNRC), DOWL has completed enhanced level floodplain studies for eight flooding sources. Table 1, lists the flooding sources included in this study which consists of 49.9 miles of 1D/2D floodplain modeling, 8.9 miles of floodway analysis, and two reservoir evaluations. This report documents the hydraulic analysis and subsequent floodplain mapping analysis. Results of the analyses will be incorporated into the Jefferson County, MT, and Incorporated Areas Digital Flood Insurance Rate Map (DFIRM) and Flood Insurance Study (FIS).

Table 1: Flooding Sources in Jefferson Countywide Study

Flooding Source	Zone	Reach Length (mi)	Floodway Length (mi)
Whitetail Creek	AE	11.5	1.1
Little Whitetail Creek	AE	3.1	-
Big Pipestone Creek	AE	13.0	7.8
Little Pipestone Creek	AE	6.0	-
Fish Creek	AE	15.3	-
Pappas Creek	AE	1.0	-
Whitetail Reservoir	A	0.0	-
Delmoe Lake	A	0.0	-

This report explains the methods and information used to determine flood risks according to standards set forth by FEMA. The hydraulic analysis for each stream includes the evaluation of the 10%, 4%, 2%, 1%, 1% plus, and 0.2% (10-yr, 25-yr, 50-yr, 100-yr, 100-yr plus, and 500-yr) annual chance (AC) flood events. DOWL completed the hydraulic analysis using the following FEMA approved data:

- LiDAR topographic data developed by Quantum Spatial, Inc. – 2019
- Field survey, hydraulic structure assessments, and hydrologic report completed by Pioneer Technical Services, Inc. – 2018

Figure 1 provides an overview of tributaries to the Jefferson River. These tributaries include Whitetail Creek, Little Whitetail Creek, Big Pipestone Creek, Little Pipestone Creek, and Fish Creek. Figure 2 shows Pappas Creek and the two reservoirs, Whitetail Reservoir and Delmoe Lake.

Upstream Little Whitetail Creek
STA: 163+92

Downstream Little Whitetail Creek
STA: 1+45.42

Upstream Whitetail Creek
STA: 605+28

Upstream Big Pipestone Creek
STA: 686+80

Whitehall

Upstream Little Pipestone Creek
STA: 321+38

Downstream Whitetail Creek
STA: 0+00

Cardwell

Downstream Little Pipestone Creek
STA: 5+19.71

Downstream Big Pipestone Creek
STA: 0+00

Downstream Fish Creek
STA: 0+00

Vendome

Renova

Silver Bow County

Upstream Fish Creek
STA: 806+12

Madison County

Towns
USGS Streamflow Gage
Hydraulic Structure
Beaverhead-Deerlodge National Forest
Big Pipestone Creek
Fish Creek
Little Pipestone Creek
Little Whitetail Creek
Pappas Creek
Whitetail Creek
Jefferson River SFHA
FEMA FIRM Panels

Data Frame Properties:

Projection: MONTANA STATE PLANE
Units: INTERNATIONAL FEET
Scale: 1 inch = 2.0 mi
Basemap: WORLD TERRAIN (ESRI)

0 0.75 1.5 3 Miles

JEFFERSON COUNTY MONTANA

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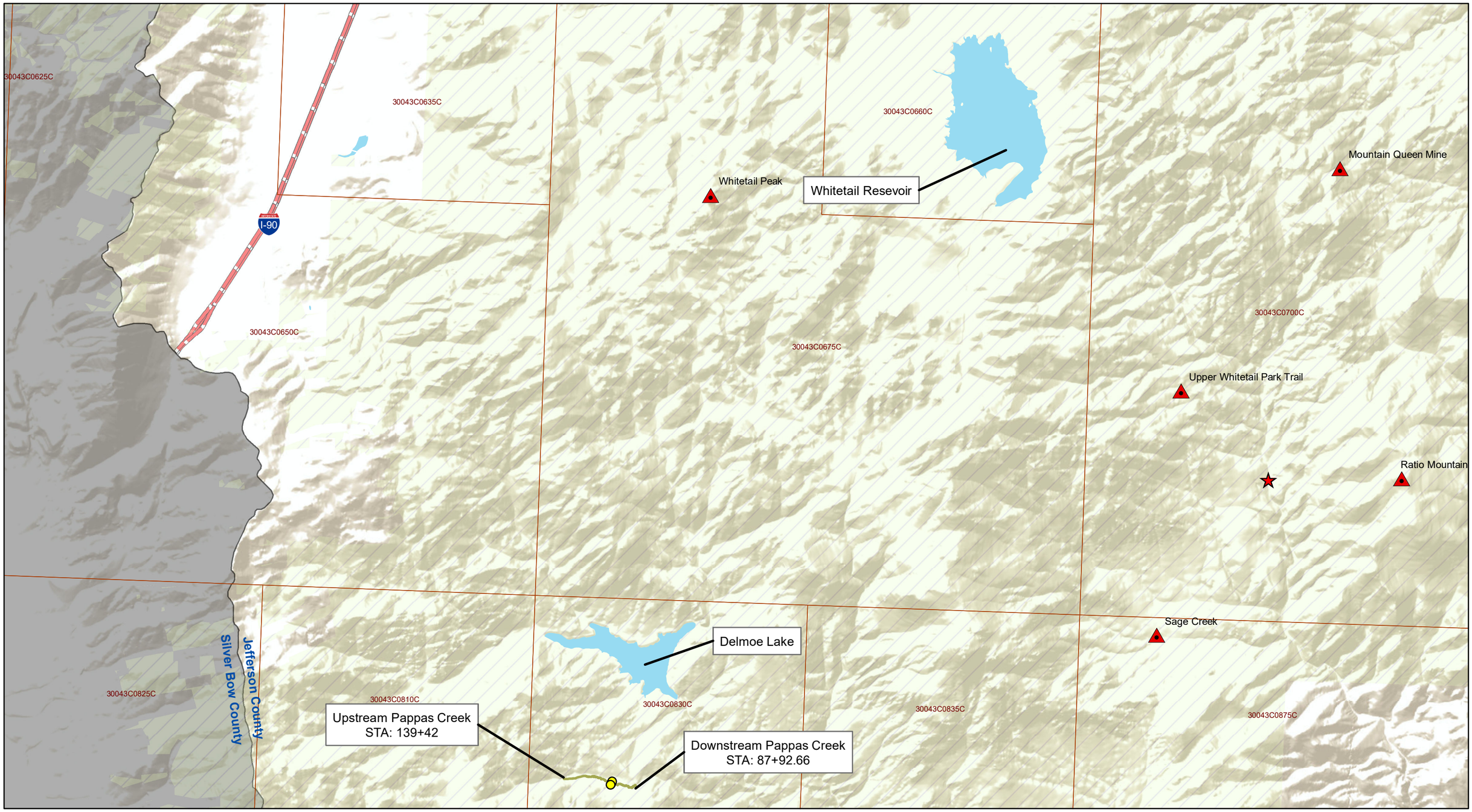
Jefferson Countywide Floodplain Study

Figure 1: *Project Overview*
Jefferson Tributaries



Towns
USGS Streamflow Gage
Hydraulic Structure
Beaverhead-Deerlodge National Forest
Pappas Creek
FEMA FIRM Panels
Reservoir Boundary

Data Frame Properties:

Projection: MONTANA STATE PLANE
Units: INTERNATIONAL FEET
Scale: 1 inch = 1.0 mi
Basemap: WORLD TERRAIN (ESRI)

N

0 0.5 1 2 Miles

JEFFERSON COUNTY MONTANA

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Jefferson Countywide Floodplain Study

Figure 2: *Project Overview*
Papas Creek, Delmoe Lake, Whitetail Reservoir

1.1 PREVIOUS STUDIES

The existing floodplain mapping for Unincorporated Jefferson County has not been modernized to Digital Flood Insurance Rate Map (DFIRM) format. The effective mapping consists of 1976 Flood Hazard Boundary Maps that were converted to Flood Insurance Rate Maps (FIRM) in 1996. All effective boundaries are outdated and represent an approximate study level. There is no effective mapping for Whitetail Reservoir.

In 1984, a Floodplain Management Study was completed on Big Pipestone Creek by the Soil Conservation Service (SCS). The study provided boundaries for the 1% annual chance (100-year) and 0.2% annual chance (500-year) events with Base Flood Elevations (BFE)s and also included a floodway. The resulting boundaries from that study are currently used to regulate development in this general area.

Another study, which is available in DFIRM format, was generated for Whitetail Creek and the community of Whitehall in 2007. This study includes a floodway with BFEs. Additionally, the effective boundary of Big Pipestone Creek was digitized and made available in DFIRM format within the community of Whitehall.

2.0 WATERSHED DESCRIPTION

2.1 WHITETAIL CREEK

The Whitetail Creek study area begins at the confluence with the Jefferson River and extends approximately 11.5 miles to the upstream study limit, defined by its confluence with Little Whitetail Creek. The watershed itself extends approximately 15 miles further northwest from the confluence of Little Whitetail Creek and Whitetail Creek into the mountain regions surrounding Whitetail Reservoir. The watershed is a large tributary to the Jefferson River, and the higher elevation areas surrounding Whitetail Reservoir consist of steep, timbered slopes. The terrain changes to more mild slopes with grass and occasional farm fields as the creek flows into the valley floor approximately 4.5 miles northwest of its confluence with Little Whitetail Creek. The immediate overbank areas of the creek within the study area are primarily farm fields, dense willows, brush, and tall native grasses. Development is fairly dense along the creek banks through the town of Whitehall and to approximately 2 miles north of Interstate 90, and sparse along the upper reaches of the study area.

2.2 LITTLE WHITETAIL CREEK

The Little Whitetail Creek study area extends approximately 3.1 miles north of the confluence of Whitetail Creek and Little Whitetail Creek. The watershed itself extends approximately 13 miles north of the upper study reach into the mountainous region south of Boulder, Montana. The higher elevation areas of the watershed consist of steep, timbered slopes while the lower elevations within the valley floor consist of

milder slopes with grass and occasional farm fields. The immediate overbank areas of the creek within the study area are primarily dense willows, brush, tall native grasses, and occasional farm fields. Development is sparse along the entire study reach.

2.3 Big Pipestone Creek

The Big Pipestone Creek study area begins near its confluence with Whitetail Creek just upstream of where Whitetail Creek flows into the Jefferson River. The study area extends approximately 13.0 miles west along Interstate 90 and terminates just upstream of Boe Lane. Boe lane is located approximately one-third mile west of the Delmoe Lake Road and Interstate 90 interchange, approximately 7 miles west of Whitehall. The watershed itself begins approximately 8.5 miles northwest of the upper study limit in the mountainous region above Delmoe Lake. The watershed consists of steep, timbered slopes above the study reach and transitions to more mild slopes with brush, willows, native grasses, and farm fields within the study reach. The immediate overbank areas of the creek within the study area are primarily dense willows, brush, tall native grasses, and farm fields. Development is intermittent along the channel banks—except near the community of Whitehall.

2.4 Little Pipestone Creek

The Little Pipestone Creek study area extends approximately 6.0 miles southwest of the confluence of Big Pipestone Creek and Little Pipestone Creek. The watershed itself extends approximately 10 miles west of the upper study reach and begins at the continental divide. The watershed consists of steep, timbered slopes above the study reach and transitions to more mild slopes with brush, willows, native grasses, and occasional farm fields along the last 2.2 miles of the study area. Development is sparse along the upper half of the study area and more intermittent along the lower reach of the study area.

2.5 Fish Creek

The Fish Creek study area begins at the confluence with the Jefferson River and extends approximately 15.3 miles west to the upstream study limit. The watershed itself extends approximately 11 miles further west from the upstream study limit into the mountains located south of Butte, Montana. The watershed consists of steep, timbered slopes above the study reach and transitions to milder slopes with brush, willows, native grasses, and farm fields within the study reach. The immediate overbank areas of the creek within the study area are primarily dense willows, brush, tall native grasses, and farm fields. There is little development or farm fields in the upper 5 miles of the study area. Light development within the study area begins approximately 1.5 miles west of Highway 55 and continues to the end of the study area. A significant area of farm fields is present east (downstream) of the Highway 55 crossing.

2.6 PAPPAS CREEK

The Pappas Creek study area begins approximately 0.25 miles east (downstream) of Delmoe Lake Road and terminates approximately 0.75 miles west (upstream) of Delmoe Lake Road. The watershed itself begins approximately 1.5 miles west of the study reach, and the entire study area is located within a mild valley with steep, mountainous side slopes. The overbank areas in the study area consists primarily of intermittent dense brush and tall native grasses.

2.7 WHITETAIL RESERVOIR

The Whitetail Reservoir study area is the area around the perimeter of the reservoir. The terrain near the reservoir water edge is mildly sloped with native grasses except at the southeast edge of the reservoir. The southeast edge is located at the base of the surrounding mountains, and the terrain is much steeper with mature stands of timber. The reservoir is fed by both small, intermittent, and perennial streams from the surrounding hillsides. No development is present in the study area.

2.8 DELMOE LAKE

The Delmoe Lake study area is the area around the perimeter of the lake. The terrain surrounding the lake is relatively steep with mature stands of timber. Three creeks flow into Delmoe Lake including International Creek to the North, Haney Creek to the Northwest, and O'Neil Creek to the west. There is minimal development along the lake shore, except for the Delmoe Lake Campground along the south shore.

3.0 CHANNEL TOPOGRAPHY

3.1 WHITETAIL CREEK

Whitetail Creek exhibits a shallow main channel with wide flood benches on the overbanks. The floodplain is bounded by high ground and steep slopes through the upper reach but becomes less defined with minimal bounding terrain as Whitetail Creek flows through Whitehall. The Highway 69 and Railroad Bridge crossings downstream of Whitehall constrict the flows to the confluence with the Jefferson River Slough. The channel slope ranges from 0.25 to 0.6% throughout the reach.

3.2 LITTLE WHITETAIL CREEK

The upstream and downstream ends of Little Whitetail Creek have a considerably broader floodplain in comparison to the middle portion of the study reach. The stream channel becomes more topographically constricted downstream of the third roadway culvert crossing and then opens back up as the stream approaches the fourth roadway culvert crossing. Little Whitetail Creek is quite sinuous and meanders across the floodplain as it navigates several culvert crossings. The stream channel again constricts slightly before the downstream confluence with Whitetail Creek. The upstream end of Little Whitetail Creek has a moderate slope of about 0.5% before steepening as it approaches the culvert crossings. The channel slope ranges between 0.3% and 0.8%.

3.3 BIG PIPESTONE CREEK

Big Pipestone Creek has a narrow channel which meanders across the broad floodplain. Flood flows access flood benches throughout the study reach except for a 0.8-mile reach where the channel is deeply incised and fully contains the 500-year flood event. The floodplain is not confined by adjacent high ground downstream of Highway 55, resulting in a broad floodplain near the town of Whitehall. The channel slope ranges from 0.25 to 0.7% throughout the study reach.

3.4 LITTLE PIPESTONE CREEK

The Little Pipestone Creek floodplain through the upper reach is narrow, shallow, and bounded by steep slopes. The main channel becomes perched as the left overbank drops rapidly in the lower reach. Most of the flood flow is conveyed through the left overbank before converging with the main channel at the confluence with Big Pipestone Creek. Slopes range between 0.7 and 1.2%

3.5 FISH CREEK

The Fish Creek channel and floodplain varies widely from upstream to downstream. The upstream reach extending downstream approximately 5 miles to 1.5 miles upstream of Highway 55, meanders slightly,

and exhibits consistent flood depths and widths. This reach has a slope of approximately 1.5% with short sections increasing to 3%. The main channel carries a large percentage of the total flood flow, resulting in narrower floodplain extents.

As Fish Creek approaches Highway 55, the channel becomes less defined. Multiple braided splits form upstream of the highway crossings. The two highway crossings result in two distinct flow paths that converge approximately 1.2 miles downstream. The channel slope is much flatter than the upstream reach at approximately 0.14% downstream of the highway. Flood flows are not confined, and flows split and re-converge at multiple locations. A large percentage of the total flood flow is conveyed in the right overbank through agricultural fields and along the railroad.

3.6 PAPPAS CREEK

The Pappas creek channel is not well defined and not easily distinguishable from aerial imagery. The floodplain is approximately 250 to 400 feet wide throughout the study reach. The slope of the bottom half of the reach is approximately 0.5% while the slope of the upper half ranges from 0.75% to 2%. The channel has mild sinuosity, and only one hydraulic structure exists in the study reach.

4.0 HYDROLOGY

Pioneer Technical Services, Inc. completed the hydrologic analyses using methods developed by the USGS including the Gage Transfer Method, Regional Regression Equation (RRE) Method, and RRE weighted At-Site method. The results of the hydrologic study are summarized in Table 2. Flow change locations are shown in Figure 3 and summarized in Table 3.

Table 2: Jefferson Countywide Flood Flows

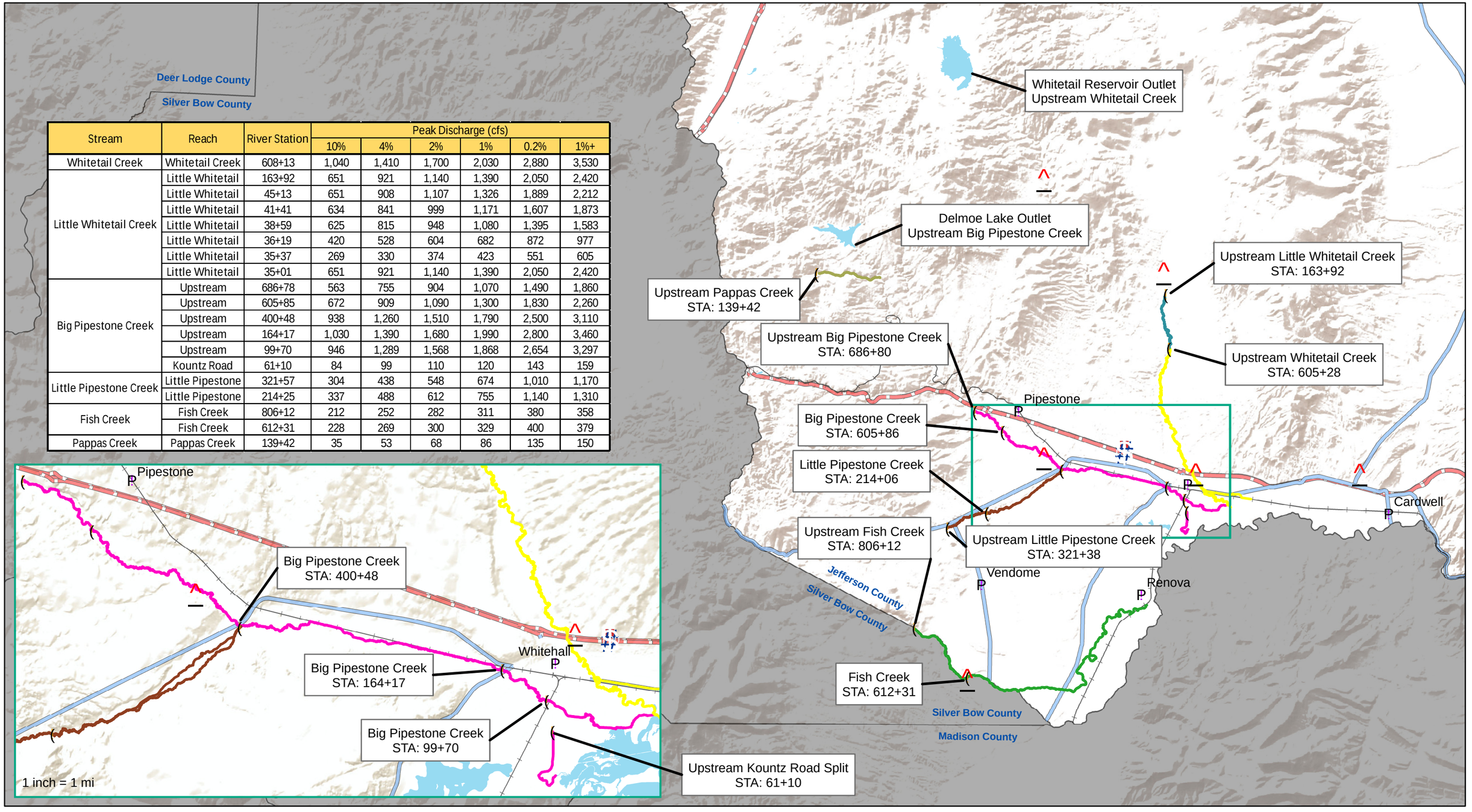
NODE ID	NODE NAME	DRAINAGE AREA (MI^2)	PEAK DISCHARGE (CFS)					
			10% AC	4% AC	2% AC	1% AC	0.2% AC	1%+ AC
			10-Year	25-Year	50-Year	100-Year	500-Year	100-Year
06027700	**Fish Creek** Near Silver Star, MT*	39	212	252	282	311	380	358
1300	**Fish Creek** upstream of Jefferson Slough Recharge	43	228	269	300	329	400	379
1200	**Fish Creek** at junction with Jefferson River	52	265	309	341	372	445	428
1100	**Pappas Creek**	3	35	53	68	86	135	150
1000	**Little Pipestone Creek** south of Montana Highway 2	41	304	438	548	674	1,010	1,170
900	**Little Pipestone Creek** upstream of junction with Big Pipestone Creek	46	337	488	612	755	1,140	1,310
800	**Delmoe Lake** Outlet	24	174	241	293	352	503	612
700	**Big Pipestone Creek** Upstream of Hot Springs Road	95	563	755	904	1,070	1,490	1,860
600	**Big Pipestone Creek** Upstream of junction with Little Pipestone Creek	114	672	909	1,090	1,300	1,830	2,260
500	**Big Pipestone Creek** upstream of Pleasant Valley Ditch	169	938	1,260	1,510	1,790	2,500	3,110
400	**Big Pipestone Creek** at junction with Jefferson River	187	1,030	1,390	1,680	1,990	2,800	3,460
300	**Little Whitetail Creek** at junction with Whitetail Creek	101	651	921	1,140	1,390	2,050	2,420
200	**Whitetail Reservoir** Outlet	19	149	208	255	308	444	536
100	**Whitetail Creek** at junction with Jefferson River	184	1,040	1,410	1,700	2,030	2,880	3,530

*USGS Gage Station

Table 3: Hydraulic Model Flow Change Locations

Stream	Reach	River Station	Peak Discharge (cfs)					
			10%	4%	2%	1%	0.2%	1%+
Whitetail Creek	Whitetail Creek	608+13	1,040	1,410	1,700	2,030	2,880	3,530
Little Whitetail Creek	Little Whitetail	163+92	651	921	1,140	1,390	2,050	2,420
	Little Whitetail	45+13	651	908	1,107	1,326	1,889	2,212
	Little Whitetail	41+41	634	841	999	1,171	1,607	1,873
	Little Whitetail	38+59	625	815	948	1,080	1,395	1,583
	Little Whitetail	36+19	420	528	604	682	872	977
	Little Whitetail	35+37	269	330	374	423	551	605
	Little Whitetail	35+01	651	921	1,140	1,390	2,050	2,420
Big Pipestone Creek	Upstream	686+78	563	755	904	1,070	1,490	1,860
	Upstream	605+85	672	909	1,090	1,300	1,830	2,260
	Upstream	400+48	938	1,260	1,510	1,790	2,500	3,110
	Upstream	164+17	1,030	1,390	1,680	1,990	2,800	3,460
	Upstream	99+70	946	1,289	1,568	1,868	2,654	3,297
	Kountz Road	61+10	84	99	110	120	143	159
Little Pipestone Creek	Little Pipestone	321+57	304	438	548	674	1,010	1,170
	Little Pipestone	214+25	337	488	612	755	1,140	1,310
Fish Creek	Fish Creek	806+12	212	252	282	311	380	358
	Fish Creek	612+31	228	269	300	329	400	379
Pappas Creek	Pappas Creek	139+42	35	53	68	86	135	150

Stream	Reach	River Station	Peak Discharge (cfs)					
			10%	4%	2%	1%	0.2%	1%+
Whitetail Creek	Whitetail Creek	608+13	1,040	1,410	1,700	2,030	2,880	3,530
Little Whitetail Creek	Little Whitetail	163+92	651	921	1,140	1,390	2,050	2,420
	Little Whitetail	45+13	651	908	1,107	1,326	1,889	2,212
	Little Whitetail	41+41	634	841	999	1,171	1,607	1,873
	Little Whitetail	38+59	625	815	948	1,080	1,395	1,583
	Little Whitetail	36+19	420	528	604	682	872	977
	Little Whitetail	35+37	269	330	374	423	551	605
	Little Whitetail	35+01	651	921	1,140	1,390	2,050	2,420
Big Pipestone Creek	Upstream	686+78	563	755	904	1,070	1,490	1,860
	Upstream	605+85	672	909	1,090	1,300	1,830	2,260
	Upstream	400+48	938	1,260	1,510	1,790	2,500	3,110
	Upstream	164+17	1,030	1,390	1,680	1,990	2,800	3,460
	Upstream	99+70	946	1,289	1,568	1,868	2,654	3,297
	Kountz Road	61+10	84	99	110	120	143	159
Little Pipestone Creek	Little Pipestone	321+57	304	438	548	674	1,010	1,170
	Little Pipestone	214+25	337	488	612	755	1,140	1,310
Fish Creek	Fish Creek	806+12	212	252	282	311	380	358
	Fish Creek	612+31	228	269	300	329	400	379
Pappas Creek	Pappas Creek	139+42	35	53	68	86	135	150



Towns
Flow Change
USGS Streamflow Gage
Beaverhead-Deerlodge National Forest
Big Pipestone Creek
Fish Creek
Little Pipestone Creek
Little Whitetail Creek
Pappas Creek
Whitetail Creek
Kountz Road Split

Data Frame Properties:

Projection: MONTANA STATE PLANE
Units: INTERNATIONAL FEET
Scale: 1 inch = 3 mi
Basemap: WORLD TERRAIN (ESRI)

0 1.5 3 6 Miles

JEFFERSON COUNTY MONTANA
DOWL
MONTANA DNRC

Jefferson Countywide Floodplain Study

Figure 3: *Flow Change Locations Jefferson Tributaries*

5.0 HYDRAULIC MODELING

The methodologies used to complete the hydraulic analysis for the Jefferson Countywide Floodplain Study are presented below.

5.1 OVERVIEW

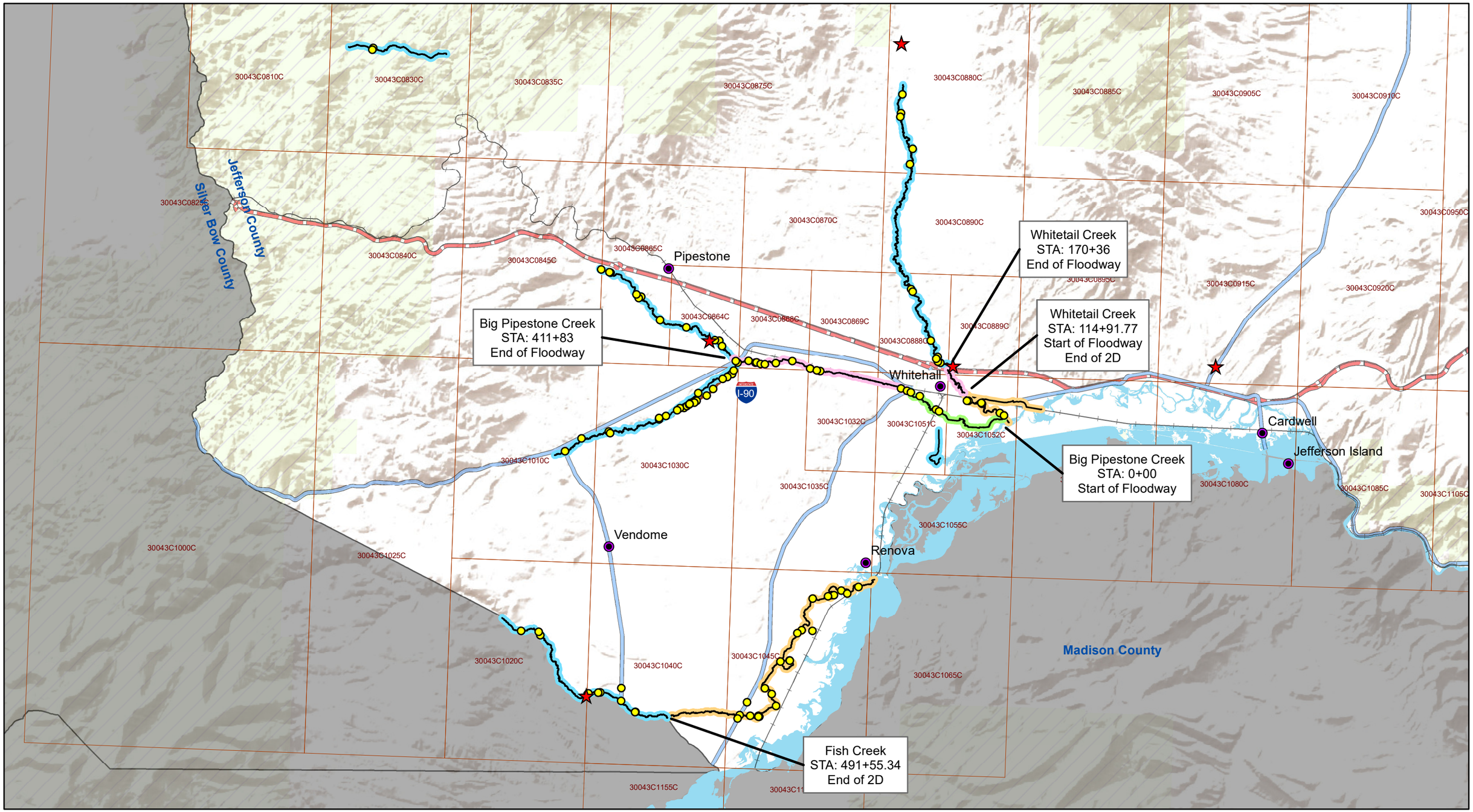
Hydraulic models for each of the study reaches were developed following guidance provided in the FEMA publication *Hydraulics: One-Dimensional Analysis (Nov 2016)* and *Hydraulics: Two-Dimensional Analysis (Nov 2016)*. DOWL used CivilGEO GeoHECRAS version 2.7.0 in conjunction with the Hydrologic Engineering Center's (HEC) River Analysis System (RAS), HEC-RAS version 5.0.7 to develop the hydraulic models. Cross sections, structure crossings, and lateral weirs represented in the one-dimensional (1D) models were developed in accordance with the *HEC-RAS River Analysis System User's Manual, Version 5.0 (Feb 2016)*.

Three approaches to modeling were employed: 1D regulatory (with and without floodway), 1D informed by two-dimensional (2D) modeling, and 2D regulatory. Figure 4 shows where each modeling approach was used. Table 4 also summarizes the model reach lengths for each stream.

Table 4: Hydraulic Modeling Approach and Reach Length

Stream	Modeling Approach	Length (mi)	Start Station	End Station
Whitetail Creek	1D Regulatory	8.2	170+36	605+28
	1D Regulatory with Floodway	9.3	114+91.77	170+36
	2D Regulatory	2.2	00+00	114+91.77
Little Whitetail Creek	1D Regulatory	3.1	01+45.42	163+92
Big Pipestone Creek	1D Regulatory	5.3	404+95	686+78
	1D Regulatory with Floodway	13.0	00+00	411+83
	1D informed by 2D	3.1	00+00	161+48
Little Pipestone Creek	1D Regulatory	6.0	02+96.01	321+57
Fish Creek	1D Regulatory	6.0	491+55.34	806+12
	2D Regulatory	9.3	00+00	491+55.34
Pappas Creek	1D Regulatory	1.0	87+92.66	139+42

Traditional 1D regulatory models were developed for both enhanced and enhanced with floodway reaches. A 2D model was used to determine the flow splits for the lower reach of the Big Pipestone Creek as well as where the Kountz Road Split originates. The downstream reaches of Whitetail Creek and Fish Creek were modeled using Regulatory 2D to more accurately map the highly braided channels, numerous split flows, and multiple confluences with the Jefferson River. Modeling approaches for 1D and 2D hydraulic analyses are documented in Section 5.4 and Section 5.5, respectively.



Towns

USGS Streamflow Gage

Beaverhead-Deerlodge National Forest

Jefferson River SFHA

FEMA FIRM Panels

Model Type

1D Regulatory

1D Regulatory with Floodway

1D Regulatory with Floodway, Informed by 2D

2D Regulatory

Data Frame Properties:

Projection: MONTANA STATE PLANE
Units: INTERNATIONAL FEET
Scale: 1 inch = 1.5 mi
Basemap: WORLD TERRAIN (ESRI)

0 0.75 1.5 3 Miles

JEFFERSON COUNTY MONTANA

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Jefferson Countywide Floodplain Study

Figure 4 : *Project Model Types*
Jefferson Tributaries

5.2 TOPOGRAPHIC MAPPING ACQUISITION

The LiDAR and field survey data were provided in the Montana State Plane coordinate system, with a Lambert Conformal Conic projection. Both data sets are referenced horizontally to the North American Datum of 1983 (NAD83-2011) and vertically to the North American Vertical Datum of 1988 (NAVD88). LiDAR units were reported in feet. The field survey was reported with horizontal units of international feet and vertical units of U.S. feet.

5.2.1.1 Incorporation of Bathymetric Survey Data

Surveyed bathymetric cross sections were collected along the lower reaches of Big Pipestone Creek and Whitetail Creek through Whitehall. This data, collected by Pioneer Technical Services, Inc., was incorporated into the LiDAR data to create a final terrain surface. First, the profile baseline was corrected based on LiDAR topography and NAIP imagery (USDA, 2017). Cross sections were then cut at each surveyed location which created a channel interpolation surface in HEC-RAS 5.0.7 that interpolates the channel geometry between cross sections along the profile baseline. This surface was exported into ArcMap 10.5 and mosaicked with the LiDAR surface. During the mosaic process, a filter was added to select the lower elevation between the LiDAR and the interpolation surface—this eliminates the possibility of higher-elevation "berms" being created along the channel. Based on inspection of the final terrain surface, the bathymetric data and LiDAR transition smoothly.

5.2.2 LiDAR Survey

Aerial topographic survey data was collected in 2018 by Quantum Spatial, Inc. for approximately 256 square miles representing all of Jefferson County. The project area required a 0.35-meter nominal post spacing and a 10-centimeter, non-vegetated vertical accuracy. More information on the topographic survey data is provided in Appendix A (LiDAR Technical Data Report, Quantum Spatial, Inc.., March 2018).

5.2.3 Field Data Collection and Survey

LiDAR data was supplemented with ground-based survey data for the floodway analysis through Whitehall on Big Pipestone Creek and Whitetail Creek. Survey data included the following:

- 98 cross sections and 19 hydraulic structures on Big Pipestone Creek
- 28 cross sections and 6 hydraulic structures on Whitetail Creek

Pioneer Technical Services, Inc. performed the field survey in 2018. Additional details of the field survey is provided in Appendix A.

5.2.4 Structure Inventory

A structure inventory was also completed by Pioneer Technical Services, Inc. in 2018. Information collected for each structure includes structure type, dimensions, material, and backwater potential. The structure inventory includes 92 structures which are described in the report provided in Appendix A.

5.3 MANNING'S ROUGHNESS COEFFICIENTS

The Manning's roughness coefficients were determined based on field observations, aerial photography, National Land Cover Database (NLCD 2018) descriptions, and recommendations in *Open-Channel Hydraulics (Chow, 1959.)*.

Review of comparable streams from *Roughness Characteristics of Natural Channels (USGS, 1967),* together with field reviews of channel bed material, vegetation, topography, and discharge were also used in selecting representative channel roughness values. The selected values are summarized in Table 5, below:

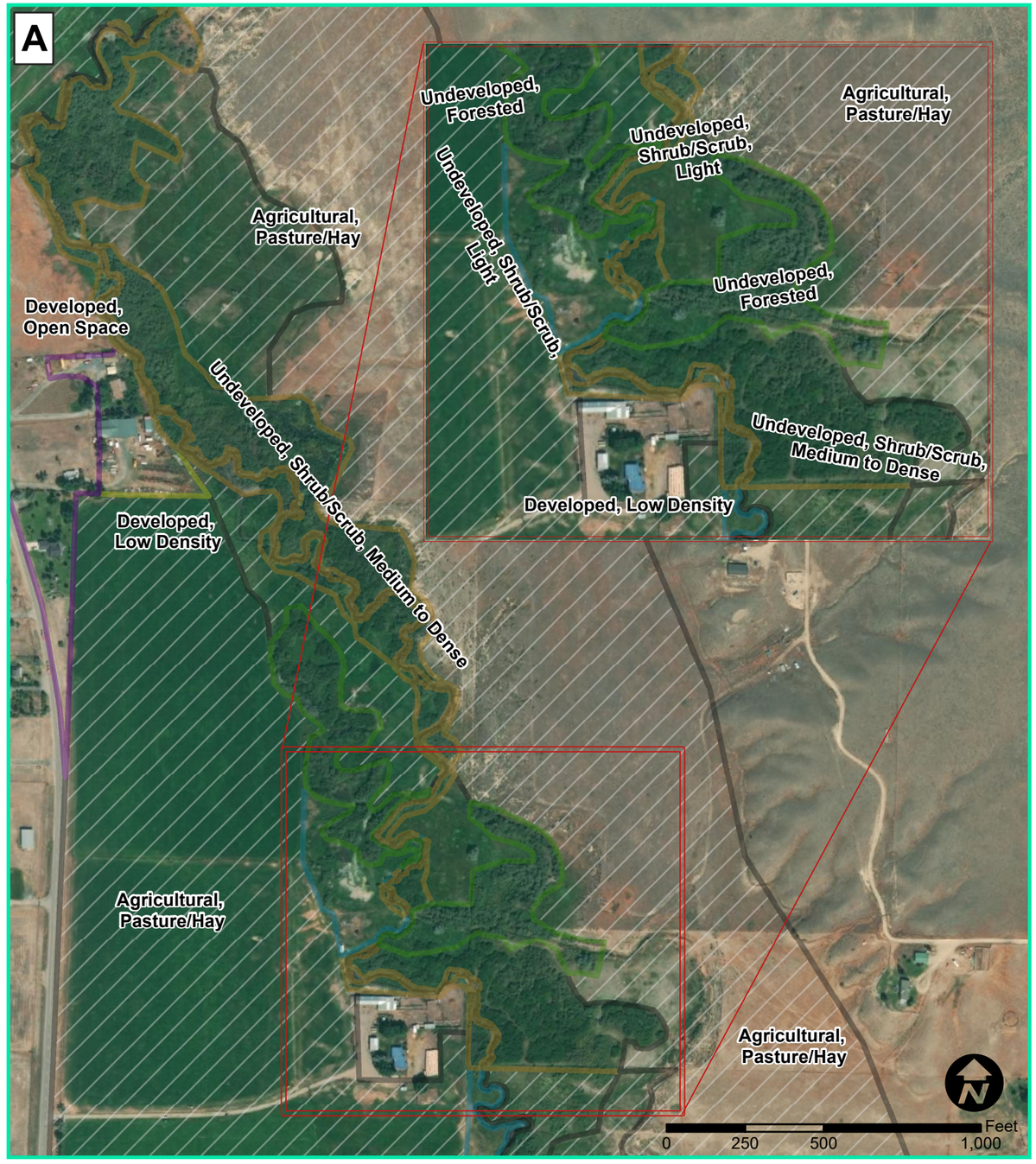
Table 5: Channel Roughness Values.

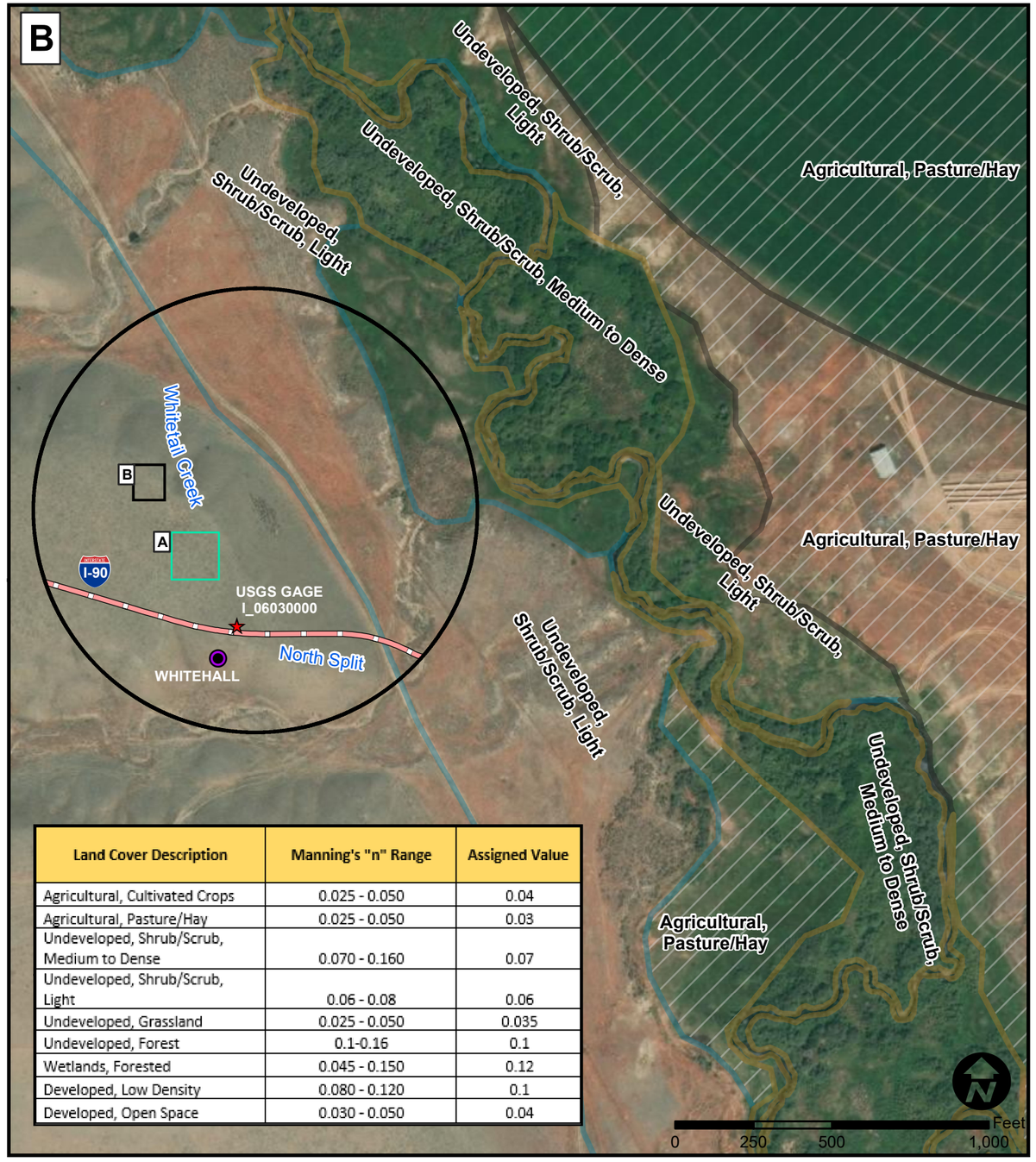
Stream	Channel Roughness Value
Whitetail Creek	0.032 - 0.150
Little Whitetail Creek	0.045 - 0.090
Big Pipestone Creek	0.032 - 0.120
Little Pipestone Creek	0.035 - 0.120
Fish Creek	0.035 - 0.120
Pappas Creek	0.090 - 0.100

Manning's roughness coefficients for the 1D models, were also used to simulate the roughness of the overbanks. Representative land covers for the study area were digitized and assigned a description and Manning's roughness coefficient. For 2D models, the entire study area was digitized in ArcMap and imported into GeoHECRAS as a landcover layer. The land cover descriptions are displayed in Figure 5 and the roughness coefficients are shown in Table 6.

Table 6: Overbank Roughness Values

Land Cover Description	Manning's "n" Range	Assigned Value
Agricultural, Cultivated Crops	0.025 - 0.050	0.040
Agricultural, Pasture/Hay	0.025 - 0.050	0.030
Undeveloped, Shrub/Scrub, Medium to Dense	0.070 - 0.160	0.070
Undeveloped, Shrub/Scrub, Light	0.06 - 0.08	0.060
Undeveloped, Grassland	0.025 - 0.050	0.035
Undeveloped, Forest	0.100 - 0.160	0.100
Water/Pond	0.08-0.012	0.010
Wetlands, Forested	0.045 - 0.150	0.120
Heavily Developed	0.016-0.035	0.025
Developed, Low Density	0.080 - 0.120	0.100
Developed, Open Space	0.030 - 0.050	0.040





Land Cover Description	Manning's "n" Range	Assigned Value
Agricultural, Cultivated Crops	0.025 - 0.050	0.04
Agricultural, Pasture/Hay	0.025 - 0.050	0.03
Undeveloped, Shrub/Scrub, Medium to Dense	0.070 - 0.160	0.07
Undeveloped, Shrub/Scrub, Light	0.06 - 0.08	0.06
Undeveloped, Grassland	0.025 - 0.050	0.035
Undeveloped, Forest	0.1-0.16	0.1
Wetlands, Forested	0.045 - 0.150	0.12
Developed, Low Density	0.080 - 0.120	0.1
Developed, Open Space	0.030 - 0.050	0.04

- Agricultural, Pasture/Hay
- Developed, Low Density
- Developed, Open Space
- Undeveloped, Forest
- Undeveloped, Shrub/Scrub, Light
- Undeveloped, Shrub/Scrub, Medium to Dense

Data Frames Properties:

Projection: MONTANA STATE PLANE
Units: INTERNATIONAL FEET
Scale: VARIABLE
Basemap: WORLD IMAGERY (ESRI)

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Figure 5: *Overbank Roughness Values - Whitetail Creek Examples*

5.4 1D Hydraulic Model Development

5.4.1 Profile Baseline

The Hydro Lines developed for the Hydrologic Analysis (Pioneer Technical Services, Inc., 2018) were used to create preliminary profiles for hydraulic modeling. Several sections of the stream centerlines were adjusted to better align with the channel. The channel centerline was established using the LiDAR and the most recent satellite imagery: 2017 National Agricultural Imagery Program (NAIP) aerial imagery (USDA, 2017). River stationing is referenced to the confluence with the downstream creek or river ("Reference Stream"), measured in feet. Starting and ending stations are shown in Table 7. The individual reach profile baselines are displayed on the work maps provided in Appendix B.

Table 7: Model Stationing

Stream name	Reach Name	Starting Station (ft)	Ending Station (ft)	Reference Stream
Whitetail Creek	Whitetail Creek	114+91.77	608+13	Jefferson River Slough
Little Whitetail Creek	Little Whitetail	01+45.42	163+92	Whitetail Creek
Big Pipestone Creek	Upstream	00+00	686+78	Whitetail Creek
	Kountz Road	00+00	61+10	Renova Split
Little Pipestone Creek	Little Pipestone Creek	02+96.01	321+57	Big Pipestone Creek
Fish Creek	Fish Creek	491+55.34	806+12	Jefferson River
Pappas Creek	Pappas	87+92.66	139+42	Big Pipestone Creek

5.4.2 Boundary Conditions

The HEC-RAS models were evaluated under the assumptions of subcritical flow and no backwater influence from other flooding sources. Normal depth was used as the downstream boundary condition for determining the water surface elevation at the downstream limit of each 1D Regulatory HEC-RAS model. Reaches combining 1D and 2D regulatory models used known water surface elevations as downstream boundary conditions for the 1D model. The upstream boundary condition of the 2D models match the downstream 1D cross section boundary condition. The final elevation from the boundary condition stage hydrograph was used as the known water surface for the 1D model downstream boundary condition. The slopes used to calculate the normal depth were obtained from the provided LiDAR data. The slopes selected for establishing the normal depth boundary condition for each creek are shown in Table 8.

Table 8: Normal Depth Slopes

Stream	Boundary Condition	Slope (ft/ft)
Whitetail Creek	Known Water Surface*	-
Little Whitetail Creek	Normal Depth	0.007
Big Pipestone Creek	Normal Depth	0.0032
Kountz Road	Normal Depth	0.0020
Little Pipestone Creek	Normal Depth	0.0083
Fish Creek	Known Water Surface*	-
Pappas Creek	Normal Depth	0.0073

*Matches water surface elevation with downstream 2D model

5.4.3 Cross Section Development

The terrain data used in developing the HEC-RAS models was extracted from the LiDAR data. The terrain surface was modified along the enhanced reaches of Big Pipestone Creek and Whitetail Creek to incorporate the bathymetry collected. GeoHECRAS Version 2.7.0 was used to place cross sections perpendicular to the direction of flow, and cross section extents were established to encompass the water surface of the 0.2% annual chance flood event. Typically, cross sections are placed with a target spacing of 300 to 500 feet, with additional cross sections added at key locations along the reach. These locations may include structure crossings, breaks in channel slope, abrupt changes in the floodplain width, and changes in flow direction.

Several cross sections in the Fish Creek, Pappas Creek, and Little Whitetail 1D Regulatory floodplain models are spaced less than 300 feet. The small peak flows of Fish Creek and Pappas Creek require a shorter cross section spacing in many areas to accurately model these flood events. The higher degree of sinuosity exhibited by Little Whitetail Creek also requires closer-spaced cross sections to accurately model the flood hydraulics through the meandering channel.

Contraction and expansion coefficients were generally set at 0.1 and 0.3, respectively. For cross sections near bridge structures, the contraction and expansion coefficients were set to 0.3 and 0.5. The coefficients were increased to 0.6 and 0.8 for consecutive roadway crossings in series.

5.4.4 Non-Conveyance Areas

Ineffective flow limits near bridges, culverts, and natural constrictions are generally set to approximate a 1:1 contraction upstream and a 2:1 expansion downstream. The expansion and contraction limits extend from the bridge faces and the ends of the culverts. Exceptions to these typical applications include structures with significant overtopping and where there are changes in flow direction near structure

openings. Review of the modeled cross sections also reveals numerous depression areas and narrow side channels that are not hydraulically connected to the main channel. These areas were also classified as ineffective to simulate hydraulic conveyance more accurately. Further explanations of the assumed ineffective flow limits are provided in Appendix E.

5.4.5 Blocked Obstructions

There are structures and buildings within the Jefferson Countywide study area that block the effective flow. These features are modeled using the blocked obstructions feature in HEC-RAS to prevent conveyance at these locations. Cross sections with blocked obstructions are documented in Appendix E.

5.4.6 Hydraulic Structures

There are 118 crossing structures modeled in the 1D study area. Crossings were defined in the hydraulic model using information provided in the survey report, hydraulic structure assessment, LiDAR data, and photographs obtained during field visits.

The field survey and structure assessment included information for 55 of these structures. Crossings that were not inventoried in the structure assessment were defined using aerial imagery, LiDAR data, and engineering judgement. Table 9 summarizes the number of structures for each creek.

Table 9: 1D Model Structure Summary

Stream	Bridges	Culverts	Total
Whitetail Creek	1	6	**7**
Little Whitetail Creek	0	5	**5**
Big Pipestone Creek	15	15	**30**
Kountz Road	0	3	**3**
Little Pipestone Creek	2	9	**11**
Fish Creek	9	0	**9**
Pappas Creek	0	3	**3**
Total	**27**	**41**	**68**

Culverts in limited detail reaches, without bathymetric survey are in some cases modeled below the thalweg elevation to match the structure inventory. Culverts were not modeled as embedded (filled-in below the thalweg elevation) because the capacity is negligible at the regulatory events and overtopping controls.

The following sections provide a description of the various structures on each stream. A summary of the bridges and culverts is presented in Table 10. The 'Structure ID' corresponds to the structure identification numbers from the hydraulic structure assessment.

Table 10: Summary of Hydraulic Structures and Key Features

Survey / Invetory Structure ID	Stream	Reach	Station	Description	Structure Type	Bridge Data					Culvert Data			
						Span Length (ft)	Bridge Width (ft)	Number of Spans	Pier Coefficients (Cd, K)	Modeling Approach	Length (ft)	Shape	Type	Dimensions
B65	Fish Creek	Fish Creek	539+72	Private Farm Field Crossing	Bridge	28.6	13.3	1	-	Energy	-	-	-	-
C65a	Fish Creek	Fish Creek	*Not Modeled*											
B66	Fish Creek	Fish Creek	565+51	Highway 41 Crossing	Bridge	56.3	22	3	1.2, 1.05	Energy	-	-	-	-
B66.5	Fish Creek	Fish Creek	593+78	Farm Field Crossing	Bridge	13.5	8	1	-	Energy	-	-	-	-
B67	Fish Creek	Fish Creek	596+29	Private Driveway Crossing	Bridge	13.8	16.5	1	-	Pressure/Weir	-	-	-	-
B68	Fish Creek	Fish Creek	610+93	Cutoff Road Crossing	Bridge	22.4	22.2	1	-	Energy	-	-	-	-
B69	Fish Creek	Fish Creek	746+16	Farm Field Crossing	Bridge	18	7.1	1	-	Pressure/Weir	-	-	-	-
B70	Fish Creek	Fish Creek	750+78	Residential Crossing	Bridge	24.2	7	1	-	Pressure/Weir	-	-	-	-
B71	Fish Creek	Fish Creek	776+10	Residential Crossing	Bridge	18	12.2	-	-	Pressure/Weir	-	-	-	-
-	Whitetail Creek	Whitetail Creek	120+44	First St. Crossing	Bridge	34.5	40.5	1	-	Pressure/Weir	-	-	-	-
-	Whitetail Creek	Whitetail Creek	158+42	Yellowstone Trail Crossing	Bridge	-	-	-	-	-	-	-	-	-
-	Whitetail Creek	Whitetail Creek	171+60	I90 Crossing	Culvert	-	-	-	-	-	206.69	Double Pipe Arch	Corrugated Steel	8.4' x 13.4'
B7	Whitetail Creek	Whitetail Creek	196+13	Baker Lane Crossing	Bridge	26.7	18	1	-	Pressure/Weir	-	-	-	-
B8.5	Whitetail Creek	Whitetail Creek	202+90	Private Crossing	Bridge	10	10.2	1	-	Pressure/Weir	-	-	-	-
B10	Whitetail Creek	Whitetail Creek	346+25	Private Crossing	Bridge	21.8	12.7	1	-	Energy	-	-	-	-
B11	Whitetail Creek	Whitetail Creek	350+89	Whitetail Road Crossing	Bridge	24.6	30	1	-	Pressure/Weir	-	-	-	-
C12	Little Whitetail Creek	Little Whitetail Creek	6+98	Private Road	Culvert	-	-	-	-	-	15.8	Circular	Corrugated Steel	4.5'
C13	Little Whitetail Creek	Little Whitetail Creek	35+17	Private Road	Culvert	-	-	-	-	-	32	Circular	Corrugated Steel	4'
C14	Little Whitetail Creek	Little Whitetail Creek	109+43	Private Road	Culvert	-	-	-	-	-	24.5	Circular	Reinforced Concrete	3'
C15	Little Whitetail Creek	Little Whitetail Creek	114+98	Private Road	Culvert	-	-	-	-	-	24.5	Circular	Reinforced Concrete	3'
C16	Little Whitetail Creek	Little Whitetail Creek	146+58	Private Road	Culvert	-	-	-	-	-	24.5	Circular	Reinforced Concrete	3'
-	Big Pipestone Creek	Upstream	99+31	Kountz Road Crossing	Bridge	51.1	25.6	1	-	Energy	-	-	-	-
-	Big Pipestone Creek	Upstream	103+07	Abandoned Railroad Crossing	Bridge	42.7	9.6	3		Pressure/Weir	-	-	-	-
-	Big Pipestone Creek	Upstream	140+97	Residential Crossing	Bridge	23.1	11.7	1	-	Energy	-	-	-	-
-	Big Pipestone Creek	Upstream	156+08	Farm Field Crossing	Bridge	29.9	9.9	1	-	Pressure/Weir	-	-	-	-
-	Big Pipestone Creek	Upstream	161+97	Highway 55 Crossing	Bridge	138.6	39.2	3	1.2, 1.05	Pressure/Weir	-	-	-	-
-	Big Pipestone Creek	Upstream	171+39	Capp Lane Crossing	Bridge	21.5	16.6	1		Pressure/Weir	-	-	-	-
-	Big Pipestone Creek	Upstream	281+36	Access Road Crossing	Culvert	-	-	-	-	-	26.6	Circular	Smooth Steel	9'
-	Big Pipestone Creek	Upstream	285+30	Irrigation Diversion	Bridge	12.1	7	1	-	Energy	-	-	-	-
-	Big Pipestone Creek	Upstream	293+66	Residential Crossing	Culvert	-	-	-	-	-	28.1	Circular	Smooth Steel	7'
-	Big Pipestone Creek	Upstream	316+74	Farm field Crossing	Culvert	-	-	-	-	-	25.4	Circular	Smooth Steel	10'
-	Big Pipestone Creek	Upstream	341+05	Farm field Crossing	Culvert	-	-	-	-	-	25.6	Circular	Smooth Steel	9'
-	Big Pipestone Creek	Upstream	359+09	Irrigation Structure	Culvert	-	-	-	-	-	40.7	Circular	Smooth Steel	3'
-	Big Pipestone Creek	Upstream	364+97	Residential Crossing	Culvert	-	-	-	-	-	24.1	Circular	Smooth Steel	9'
-	Big Pipestone Creek	Upstream	372+29	Farm field Crossing	Bridge	16.4	3	1	-	Pressure/Weir	-	-	-	-
-	Big Pipestone Creek	Upstream	373+42	Farm field Crossing	Bridge	7.3	25	1	-	Pressure/Weir	-	-	-	-
-	Big Pipestone Creek	Upstream	384+43	Farm field Crossing	Bridge	30.9	3.1	1	-	Pressure/Weir	-	-	-	-
-	Big Pipestone Creek	Upstream	405+75	Highway 2 Crossing	Bridge	75	30.8	4	1.2, 1.05	Energy	-	-	-	-
B17	Big Pipestone Creek	Upstream	437+78	Farm field Crossing	Bridge	16.1	14	1		Pressure/Weir	-	-	-	-
D17.5	Big Pipestone Creek	Upstream	449+91	Diversion Structure	Culvert	-	-	-	-	-	9.8	Box	Reinforced Concrete	9.8' x 4.7'
-	Big Pipestone Creek	Upstream	449+91	Farm Field Crossing	Culvert	-	-	-	-	-	21.1	Circular	Corrugated Steel	2.5'
C18	Big Pipestone Creek	Upstream	455+43	Farm field Crossing	Culvert	-	-	-	-	-	25.3	Double Ellipse	Smooth Steel	4.2' x 4.8'
-	Big Pipestone Creek	Upstream	459+58	Farm Field Crossing	Culvert						16.8	Circular	HDPE	1.5'
B19	Big Pipestone Creek	Upstream	513+77	Residential Crossing	Bridge	9.4	14	1		Pressure/Weir	-	-	-	-
C20	Big Pipestone Creek	Upstream	557+18	Spackman Road Crossing	Culvert	-	-	-	-	-	60	Circular	Corrugated Steel	9'
C21a	Big Pipestone Creek	Upstream	606+26	Hot Springs Road Crossing	Culvert	-	-	-	-	-	62	Circular	Smooth Steel	2'
B21	Big Pipestone Creek	Upstream	606+26	Hot Springs Road Crossing	Bridge	30.5	22.2	1		Pressure/Weir	-	-	-	-
B23	Big Pipestone Creek	Upstream	615+33	Residential Crossing	Bridge	53.5	4	3		Pressure/Weir	-	-	-	-
C25	Big Pipestone Creek	Upstream	671+91	Farm field Crossing	Culvert	-	-	-	-	-	12	Triple Ellipse	Corrugated Steel	2.8' x 4.1'
C26	Big Pipestone Creek	Upstream	683+35	Boe Lane Crossing	Culvert	-	-	-	-	-	18	Ellipse	Smooth Steel	5.1' x 5.6'
-	Kountz Road	Kountz Road	02+07	Kountz Road Crossing	Culvert	-	-	-	-	-	32	Circular	Reinforced Concrete	5'
-	Kountz Road	Kountz Road	20+37	Piedmont Road Crossing	Culvert	-	-	-	-	-	28	Circular	Reinforced Concrete	4'
-	Kountz Road	Kountz Road	21+21	Private Road Crossing	Culvert	-	-	-	-	-	31	Triple Circular	Reinforced Concrete	2.5'
B27	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled*											
B27.5	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]											
C28	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]											

B30	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
-	Little Pipestone Creek	Little Pipestone Creek	28+85	Inline Weir									
-	Little Pipestone Creek	Little Pipestone Creek	35+93	Inline Weir									
-	Little Pipestone Creek	Little Pipestone Creek	45+26	Inline Weir									
B31	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
-	Little Pipestone Creek	Little Pipestone Creek	49+36	Inline Weir									
-	Little Pipestone Creek	Little Pipestone Creek	51+68	Inline Weir									
C32a	Little Pipestone Creek	Little Pipestone Creek	67+26	Private Crossing	Culvert	-	-	-	-	-	50	Circular	Corrugated Steel	4.5'
C32	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
C33	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
B34	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
D34.5	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
B35	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
C36	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
B37	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
C38	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
B39	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
B39.5	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [1]										
C40	Little Pipestone Creek	Little Pipestone Creek	113+79	Private Crossing	Culvert	-	-	-	-	-	15.8	Ellipse	Smooth Steel	3.15' x 2.25'
	Little Pipestone Creek	Little Pipestone Creek	113+79	Private Crossing	Culvert	-	-	-	-	-	15.8	Circular	Smooth Steel	3.5'
C41	Little Pipestone Creek	Little Pipestone Creek	123+57	Spackman Road	Culvert	-	-	-	-	-	33.8	Circular	Corrugated Steel	7.5'
C41a	Little Pipestone Creek	Little Pipestone Creek	*Not Modeled* [2]										
C42	Little Pipestone Creek	Little Pipestone Creek	222+02	Private Crossing	Culvert	-	-	-	-	-	28.5	Circular	Corrugated Steel	6'
	Little Pipestone Creek	Little Pipestone Creek	222+02	Private Crossing	Culvert	-	-	-	-	-	20.3	Circular	Corrugated Steel	2.5'
B43	Little Pipestone Creek	Little Pipestone Creek	270+34	Residential Crossing	Bridge	13.8	14.2	1	-	Pressure/Weir	-	-	-	-
B44	Little Pipestone Creek	Little Pipestone Creek	306+81	Highway 41 Crossing	Bridge	74.7	22.4	4	-	Energy	-	-	-	-
C45	Pappas Creek	Pappas Creek	106+73	Delmoe Lake Road	Culvert	-	-	-	-	-	28.1	-	-	-
C45a	Pappas Creek	Pappas Creek	106+73	Delmoe Lake Road	Culvert	-	-	-	-	-	32.6	-	-	-
C45b	Pappas Creek	Pappas Creek	106+73	Delmoe Lake Road	Culvert	-	-	-	-	-	32.1	-	-	-

Notes:

1 Located off the new profile baseline. No control to boundary.

2 Negligble Capacity

5.4.7 Lateral Weirs

Lateral weirs were used to simulate flows spilling out of the main channel along Big Pipestone Creek, Whitetail Creek, and Little Whitetail Creek. Table 11 summarizes the lateral weir location, the physical condition being modeled, and the assumed weir coefficient. Lateral weir coefficients were selected from the *HEC-RAS Two-Dimensional Modeling User's Manual* based on topography.

Table 11: Lateral Weirs

Stream	Reach	Weir Starting Station	Physical Condition	Weir Coefficient	Optimized (Y/N)
Big Pipestone Creek	Upstream	102+60	Kountz Road Split	-	N
	Kountz Road	49+98	Roadway Overtopping	-	N
	Kountz Road	42+13	Roadway Overtopping	-	N
Whitetail Creek	Whitetail Creek	119+40	Roadway Overtopping	2.6	N
Little Whitetail Creek	Little Whitetail Creek	47+17	Roadway Overtopping	2.6	Y

5.4.7.1 Big Pipestone Creek, Main Reach - Sta. 102+60

The lateral weir at Sta. 102+60 is located between the railroad tracks and Kountz Road, just south of the town of Whitehall. There is a perched irrigation ditch in the right overbank that spills and directs flow south along Kountz Road. The weir is not optimized in the model because the amount of flow spilling south was determined using the supplemental 2D model.

5.4.7.2 Kountz Road Split – Sta. 49+98

The lateral weir at Sta. 49+98 runs along the crest of Kountz Road from cross section 5001 to 4403, along the Kountz Road flow split. There is an irrigation ditch that runs perpendicular to flow patterns between cross section 4242 and 4403 that creates backwater which spills east over Kountz Road and flows back into Big Pipestone creek. The 2D model shows approximately 3 cfs and 9 cfs overtopping Kountz Road at this location for the 100-year and 500-year floods, respectively. This small amount of overtopping flow is deemed negligible and was neglected in further modeling efforts. Because of the small amount of overtopping flow, this lateral weir is not optimized in the 1D regulatory model.

5.4.7.3 Kountz Road Split – Sta. 42+13

The lateral weir at Sta. 42+13 runs along the crest of Kountz Road from cross section 4242 to 3329 along the Kountz Road flow split. Water spills Kountz Road at this location because of backwater created by the abandoned railroad tracks and Piedmont Road located just downstream. All overtopping flow continues east along the toe of Piedmont Road and flows back into Big Pipestone creek. The 2D model shows approximately 5 cfs and 11 cfs overtopping Kountz Road at this location for the 100-year and 500-year

floods, respectively. This small amount of overtopping flow is deemed negligible and was not included in further modeling efforts. Because of the small amount of overtopping flow, this lateral weir is not optimized in the 1D regulatory model.

5.4.7.4 Whitetail Creek, Main Reach –Sta. 119+40

The lateral weir at Sta. 119+40 runs along the crest of Highway 69 from cross section 11491.77 to 11946. At the most downstream end of the weir, calculated overtopping of Highway 69 was 0.03 cfs and 20.99 cfs for the 500-year and 100-year plus flood events, respectively. The overtopping flow travels east along the ditch between the highway and railroad before converging with the main channel of Whitetail Creek. The small amount of flow was deemed negligible and was not considered when developing the 2D regulatory model which begins immediately downstream of cross section 11491.77.

5.4.7.5 Little Whitetail Creek –Sta. 47+17

The lateral weir at Sta. 47+17 was modeled in conjunction with a culvert to describe overtopping flows at a private roadway crossing near the downstream end of Little Whitetail Creek. The complex meander pattern of Little Whitetail Creek parallel to this private roadway warranted implementation of this lateral weir, which indicated large amounts of overtopping flow. At the most downstream end of the lateral weir, the calculated overtopping flow is approximately 382 cfs, 591 cfs, 766 cfs, 967 cfs, 1499 cfs, and 1815 cfs for the 10-year, 25-year, 50-year, 100-year, 500-year, and 100-year plus flood events, respectively.

5.5 CRITICAL DEPTHS

There are several locations within the various hydraulic models that default to critical depth. Table 12 summarizes these occurrences and a brief description of why critical depth is a reasonable solution. Many of these occur at downstream bridge cross sections during flood events that overtop the bridge. Critical depth is reasonable at these locations because flow over non-submerged weirs can be expected to pass through critical depth. Other instances of critical depth are associated with steep channel reaches or where the cross section geometry constricts the flow, resulting in increased velocities and corresponding water surfaces near critical depth.

Table 12: Computed Critical Depth Locations

Stream	Reach	Cross Section				Description
			1%	0.2%	+1%	
Big Pipestone Creek	Upstream	51381	X	X	X	Bridge Crossing
		28503			X	Bridge Crossing
		28102		X		Bridge Crossing
Whitetail Creek	Whitetail Creek	60528	X	X	X	Constricted Cross Section Geometry
		43281	X			Constricted Cross Section Geometry
		35089		X	X	Bridge Crossing
		33756	X			Constricted Cross Section Geometry
		32516	X			Constricted Cross Section Geometry
		25295	X	X		Constricted Cross Section Geometry
		24225	X	X	X	Constricted Cross Section Geometry
		15842		X	X	Bridge Crossing
Little Whitetail Creek	Little Whitetail Creek	11478	X	X	X	Bridge Crossing
Pappas Creek	Pappas Creek	10649	X	X	X	Bridge Crossing

5.6 2D Hydraulic Model Development

5.6.1 Boundary Conditions

Inflow hydrographs were used to define flows entering the system. Internal boundary conditions were developed by adding the flow rate difference between the flow change locations to the respective inflow hydrographs. The flood flow was held constant until the downstream boundary condition reached steady-state. External boundary conditions are established at the most downstream cross section of the upstream 1D model.

Table 13: Summary of 2D Simulation Times

Stream	Ramp Up Time (hrs.)	Total Simulation Time (hrs.)
Fish Creek	10	20
Whitetail Creek	10	12

Flows exiting the system are simulated assuming normal depth, and the corresponding stream slope was determined by measuring the downstream terrain slope. These boundary conditions are located at the downstream confluences with the Jefferson River. Table 14 summarizes the boundary conditions for each 2D model.

Table 14: Summary of 2D Boundary Conditions

Stream	Boundary Condition ID	Control	Description
Fish Creek	BC-01	Inflow Hydrograph	1D Connection
	BC-02	Normal Depth	Slope = 0.0114
	BC-03	Normal Depth	Slope = 0.0019
	BC-04	Inflow Hydrograph	Flow Change Location
	BC-05	Normal Depth	Slope = 0.0011
	BC-07	Normal Depth	Slope = 0.0014
	BC-08	Normal Depth	Slope = 0.0014
	BC-14	Normal Depth	Slope = 0.003
Whitetail Creek	BC-01	Inflow Hydrograph	1D Connection
	BC-02	Normal Depth	Slope = 0.0060
	BC-03	Normal Depth	Slope = 0.0010
	BC-04	Normal Depth	Slope = 0.0105
	BC-05	Normal Depth	Slope = 0.0286

5.6.2 2D Flow Options

The Full Momentum method for the final 2D model results were used to improve stability and accuracy in the final model results. Using the full momentum method in conjunction with the Courant Adjusted Time Step reduced the continuity error and removed velocity "hot spots" within the mesh. Courant maximum and minimum values were selected based on *HEC-RAS 2D User's Manual, Chapter 4* for the Full Momentum equations. Initial conditions were used to stabilize the model. Flow was gradually added to the model over a 10 hour period, increasing from 0 cfs to the full flood flow.

Typical mesh size was selected to accurately capture changes in the terrain and land cover. Variable mesh zones of higher detail were added around buildings and complex flow locations. Mesh zones of lower detail were added between split reaches to reduce the total cell count were possible.

5.6.3 Breaklines

Breaklines were placed in areas where higher hydraulic detail was required and to prevent "leaking" cells. These areas include roadways, berms, spill points, ditch banks, and low flow channels, among others. Cell spacing along breaklines vary depending on the level of detail needed.

5.6.4 Hydraulic Structures

Hydraulic structures in 2D flow areas were modeled using SA/2D Connections culverts and inline weirs. Culverts, single-span bridges, and inline weirs were modeled using SA/2D connections. The terrain was adjusted at these locations to remove the road embankment and to place the culvert at the surveyed invert. Single-span bridges were modeled as box culverts with increased roughness to represent the stream channel. Multiple span bridges were modeled assuming a series of parallel box culverts with increased roughness to represent the channel.

Several surveyed structures were not included in the Fish Creek and Whitetail Creek 2D models. Some of these structures, such as B3.5 and B4 on Whitetail Creek, are in poor condition and would likely be swept away during flooding. Others, including C1a and B1, have negligible capacity and would quickly overtop during flood flows and would not significantly affect hydraulic performance (see Figure 6). Table 15 summarizes the hydraulic structures included in the 2D models.

Figure 6: Examples of Hydraulic Structures Not Included in 2D Flow Areas

Table 15: Summary of 2D Hydraulic Structures

Structure ID	Stream	Description	Feature Type	Modeling Approach	Bridge Data	Culvert Data			
					Pier Width (ft)	Length (ft)	Shape	Type	Dimensions
R276	Fish Creek	Railroad	Culvert	Culvert	-	32.41	Circular	Corrugated Steel	2'
C278	Fish Creek	Franich Lane	Culvert	Culvert	-	26.64	Circular	Corrugated Steel	2'
C277	Fish Creek	Highway 55	Culvert	Culvert	-	67.3	Circular	Reinforced Concrete	3'
B63	Fish Creek	Highway 55	Bridge	Multiple Culverts	1.5	24.6	Box	-	19' x 5'
C63a	Fish Creek	*Not Modeled* [1]							
C64	Fish Creek	Highway 55	Culvert	Culvert	-	81.3	Circular	Reinforced Concrete	3'
B62	Fish Creek	Private Road	Bridge	Culvert	-	16.3	Box	-	7.3' x 16.3'
B61.7	Fish Creek	Private Road	Bridge	Culvert	-	21.9	Box	-	5.15' x 21.9'
C61	Fish Creek	Irrigation	Culvert	Culvert	-	23.8	Arch	Corrugated Steel	6.3' x 23.8'
B61.3	Fish Creek	Private Road	Bridge	Culvert	-	14.1	Box	-	3.2' x 27.4'
B60.5	Fish Creek	*Irrigation Diversion*							
B60	Fish Creek	Private Road	Bridge	Culvert	-	5	Box	-	1.57' x 22.5'
C59	Fish Creek	Private Road	Culvert	Culvert	-	24	Circular	Corrugated Steel	9'
B58	Fish Creek	*No Structure found*							
B57	Fish Creek	Private Road	Bridge	Culvert	-	14	Box	-	2.2' x 22.1'
B56	Fish Creek	Private Road	Bridge	Culvert	-	6.2	Box	-	2.4' x 22.7'
B52	Fish Creek	Private Road	Bridge	Culvert	-	5	Box	-	1.65' x 22.8'
C53	Fish Creek	Private Road	Culvert	Culvert	-	20	Circular	Corrugated Steel	2'
C51	Fish Creek	Franich Ln	Culvert	Culvert	-	25.4	Circular	Corrugated Steel	5'
C50	Fish Creek	Private Road	Culvert	Culvert	-	20	Arch	Corrugated Steel	4.6' x 6.1'
B49	Fish Creek	Private Road	Bridge	Inline Weir	-	23.6	-	-	-
C48	Fish Creek	Private Road	Culvert	Culvert	-	20.3	Arch	Corrugated Steel	3.8' x 6.0'
	Fish Creek	Private Road	Culvert	Culvert	-	30	Circular	Corrugated Steel	1.5'
C47	Fish Creek	Franich Ln	Culvert	Culvert	-	30.1	Circular	Corrugated Steel	7'
C46.5	Fish Creek	*Not Modeled* [2]							
R46	Fish Creek	Railroad	Bridge	Multiple Culverts	2.5	9.9	Box	-	14.6' x 5.5'
B1	Whitetail Creek	*Not Modeled* [2]							
C1a	Whitetail Creek	*Not Modeled* [2]							
B3	Whitetail Creek	*Not Modeled* [2]							
B3.5	Whitetail Creek	*Not Modeled* [2]							
B4	Whitetail Creek	*Not Modeled* [2]							
B5	Whitetail Creek	*Not Modeled* [2]							
WHI_1.98	Whitetail Creek	Railroad	Bridge	Multiple Culverts	-	25.5	Box	-	13.8' x 5.75'
						25.5	Box	-	13.8' x 6.75'
						25.5	Box	-	13.8' x 5.75'
						25.5	Box	-	13.8' x 5.75'
WHI_2.05	Whitetail Creek	MT Highway 69	Bridge	Multiple Culverts	-	29.8	Box	-	38.2' x 5.56'
						29.8	Box	-	9.8' x 3.66'
R273	North Split	Railroad	Culvert	Culvert	-	50.1	Circular	-	3'
C1	North Split	MT Highway 69	Culvert	Culvert	-	94.55	Box	-	4' x 5.33'
C7	North Split	MT Highway 69	Culvert	Culvert	-	98.4	Circular	-	2.5'
C6	North Split	Mormon Lane	Culvert	Culvert	-	53.31	Circular	Reinforced Concrete	1.17'
C5	North Split	Private Road	Culvert	Culvert	-	43.08	Circular	Corrugated Steel	1.17'
C4	North Split	Private Road	Culvert	Culvert	-	30.71	Circular	Corrugated Steel	1.83'
C3	North Split	Private Road	Culvert	Multiple Culverts	-	51.05	Circular	Corrugated Steel	1.83'
					-	54.69	Circular	Corrugated Steel	1.17
C2	North Split	Private Road	Culvert	Culvert	-	47.28	Circular	Corrugated Steel	1.33'

Notes:

[1] Not located in 2D mesh

[2] Negligble Capacity

5.7 CONVEYANCE OBSTRUCTIONS

Buildings located within the 2D flow area were modeled using the 2D Conveyance Obstruction tool within GeoHECRAS. Structures were identified using the building footprints data from the LiDAR data provided by Quantum Spatial, Inc., and were then assigned a building height. The buildings are then extruded from the HEC-RAS terrain file. Any identified structures in the aerial imagery not captured in the building footprint data were manually digitized and assigned as obstructions.

5.8 FISH CREEK

Fish Creek was split into a Regulatory 1D and Regulatory 2D model. The 1D model reach meanders along the boundary between Jefferson and Silverbow counties. The downstream boundary conditions for the 1D model were determined from the upstream 2D model results.

The upstream end of the 2D model starts at station 491+55.34. Upstream of Highway 55, Fish Creek is extremely braided with flow depths typically less than two feet. Water crosses the highway in two locations where the floodplain splits. Approximately 1.5 miles downstream, the split flows converge. From here to the confluence with the Jefferson River, the stream splits and converges multiple times with shallow depths exhibited in both the channel and overbanks.

A large irrigation ditch is present downstream of Highway 55. It was assumed that this ditch would be flowing full, with no flood-flow carrying capacity. To remove the conveyance capacity of the ditch, its terrain was blocked out using the Conveyance Obstruction tool in GeoHECRAS. This terrain blockage prevented flood flows from either entering or exiting the ditch.

Road crossing “B49” appears to be blocked by debris according to the structural inventory photos (Figure 7) and was therefore modeled as a 2D connection with no opening, which forces overtopping. This approach aligns with the provided structure inventory assessment of the bridge’s condition (Poor) and backwater potential (High) (Pioneer Technical Services, Inc.).

Figure 7: Upstream Face of Structure B49 (left) and Accumulated Debris on Upstream Face (right).

Bridge “B63” and “R46” are two- and three-span bridges, respectively. Both bridges have piers that are comprised of a group of cylindrical wooden piers. These have been modeled as multi-cell box culverts. C63a was not modeled because there is no flow from Fish Creek being conveyed to it. Structure 60.5 is located on an irrigation ditch. Structure C46.5 has negligible capacity and the majority of the water flows through the overbanks and is located within the backwater of the Jefferson River Floodplain. To be conservative, C65a in the upstream 1D model of Fish Creek was not modeled because it diverts flows to an irrigation ditch.

The confluence of Fish Creek and the Jefferson River is complex. Based on the mapping, boundary water from the Jefferson River backs up to Franich Lane. Figure 8 shows the flow patterns and mapping boundaries in this area.

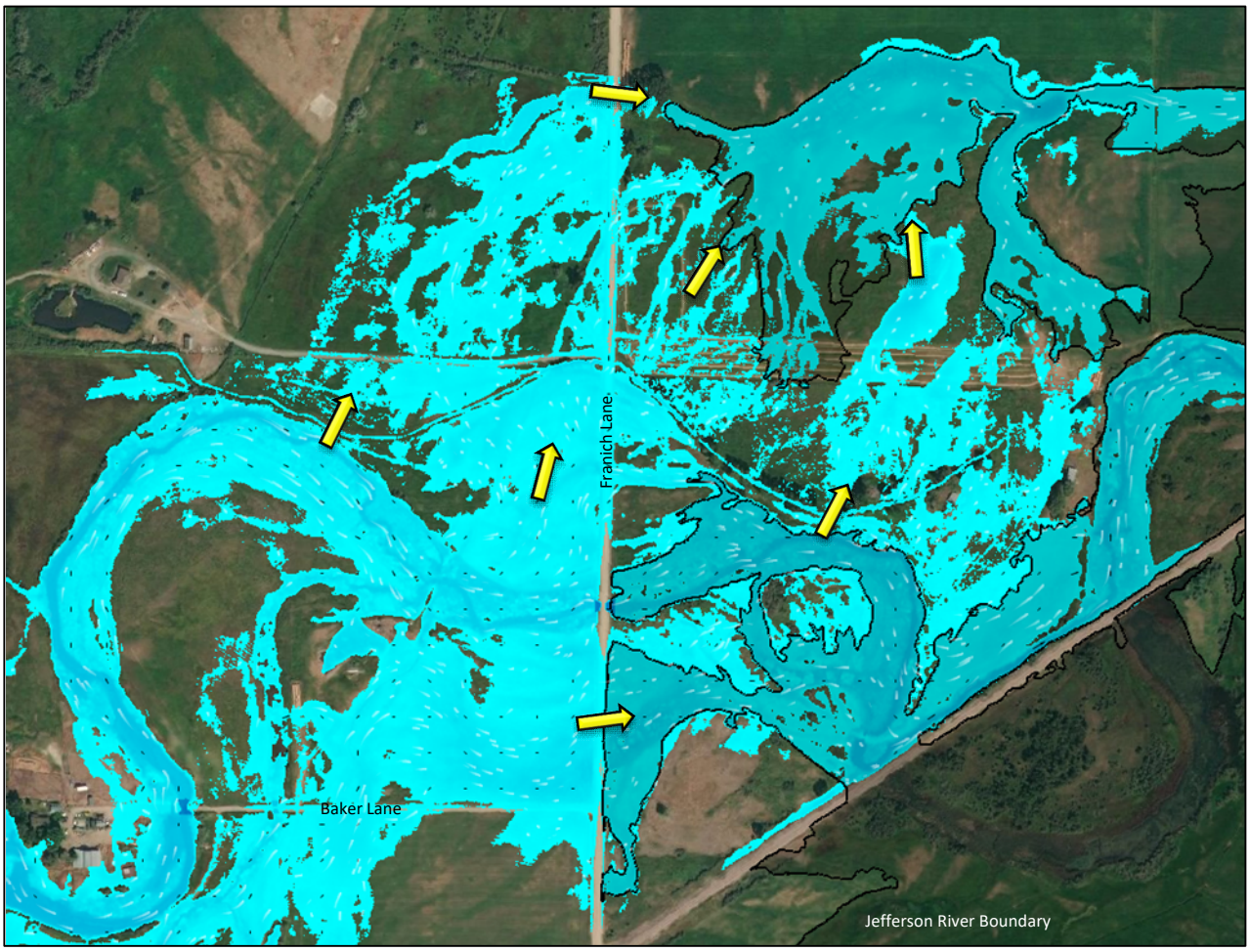


Figure 8: Flow Patterns at Confluence with Jefferson River

5.9 Big Pipestone Creek

1D and 2D models were developed for Big Pipestone Creek as well. The 2D model was used to inform the 1D model at the Kountz Road flow change. The initial 1D computational model was unable to reach a solution using numerous optimized lateral weirs, so a 2D model was implemented with monitoring lines to determine the flow splits.

The 2D model begins at Highway 55 and terminates at the confluence with Whitetail Creek. The 2D model provides refined information for complex areas including overtopping locations, roadways, irrigation ditches, and key flow split locations, among others. Figure 9 shows the monitoring line used to determine the flow split.

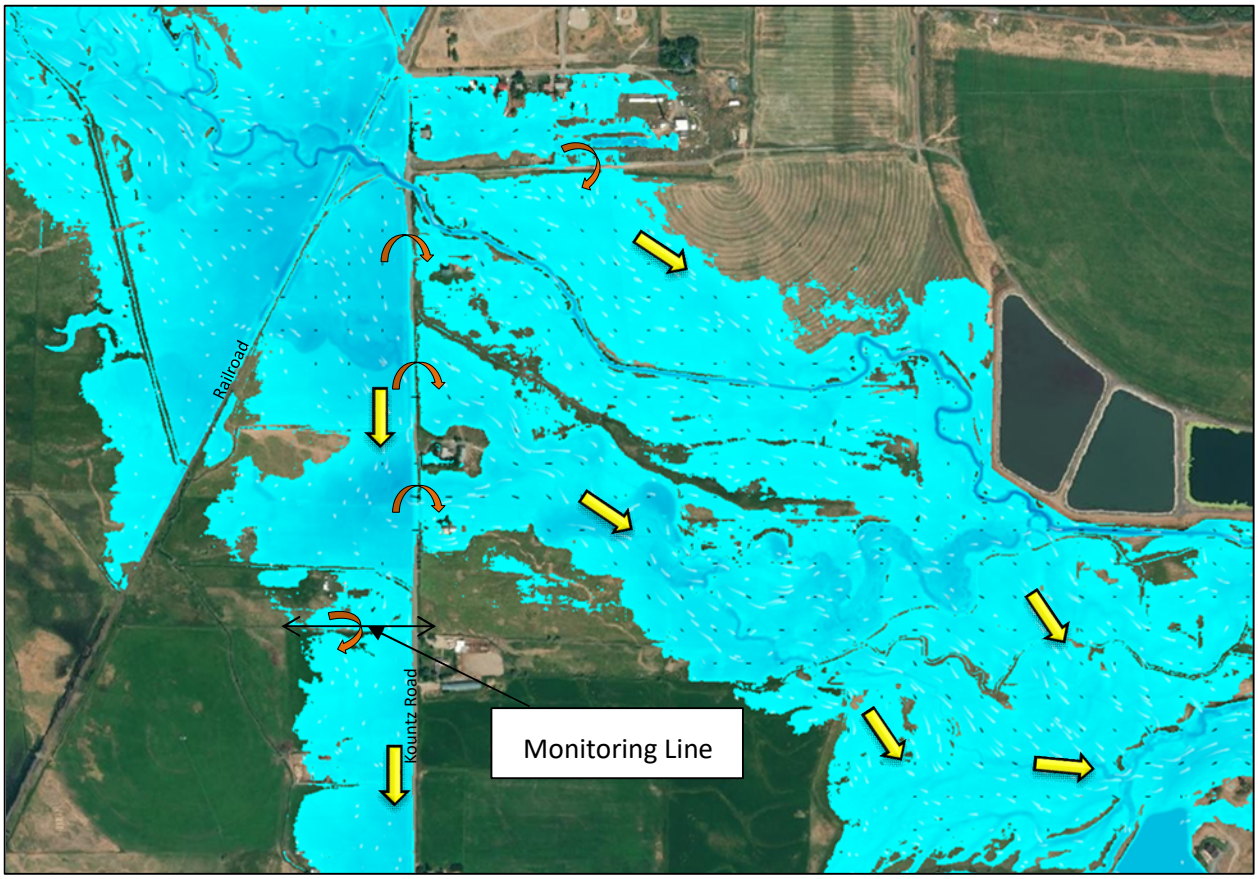


Figure 9: Big Pipestone Creek Flow Split Patterns

The irrigation ditch just west of Kountz Road in the right overbank was modeled using a 2D flow area connection in conjunction with a weir. The weir crest geometry was extracted using the ditch high point profile to simulate the backwater generated from the ditch as well as the flow spilling south along Kountz Road. This information was used to establish the "Kountz Road" flow split. Similarly, the irrigation ditch was used in determining the flow spilling east across the road surface and back into the Big Pipestone Creek main channel and was also modeled using a 2D flow area connection and weir. Modeling the irrigation ditch high point as a weir is more representative in determining the quantity of flow spilling east over Kountz Road.

2D boundary condition lines are placed at each location where flow leaves the model. Both BC-02 and BC-03 are located along the north model boundary and quantify the amount of flow that overtops the railroad tracks and Sugar Beet Row, ultimately leaving the model. Approximately 4 cfs and 10 cfs leave the model at "BC-02" for the 100-year and 500-year floods, respectively. Approximately 21-cfs and 37-cfs leave the model at "BC-03" for the 100-year and 500-year floods, respectively. This represents less than 1.5% of

the total flow leaving the model for the 100- and 500-year floods at both boundaries and is considered to be negligible. The model extents were therefore not extended to encompass the inundation limits downstream. Neglecting these overtopping flows does not impact the Kountz Road flow split values.

The 2D model was also used to quantify the amount of flow spilling Kountz Road along the south flow split. A combined total of 8-cfs and 20-cfs spills east over Kountz Road at two different locations and eventually flows back into Big Pipestone Creek. Again, the relative magnitude of the flow exiting the model at these two overtopping locations is negligible and the model was not extended to encompass the inundation limits downstream.

Ineffective flow limits in the right overbank from station 0 to station 66+42 were used to model the worst-case scenario. These ineffective flow limits help in matching the supplemental 2D model results. Ineffective flow limits were placed along the high berm that appears to separate Big Pipestone Creek and the Jefferson River.

Several smooth steel culverts are located along this reach. These culverts are modeled assuming a Manning's roughness value of 0.014 and are simulated as concrete pipes in HEC-RAS for determining hydraulic losses.

The lower reach of Big Pipestone Creek was extended 0.5 miles beyond the original scoped extents, to the confluence with Whitetail Creek. This was done to fully map the flood risks between the two streams and to fill a gap in the Jefferson River floodplain mapping. The floodplain mapping interrelationships between the Jefferson River Slough, Whitetail Creek, and Big Pipestone Creek are shown in Appendix B, Big Pipestone Creek Map 1.

5.10 LITTLE PIPESTONE CREEK

To accurately simulate flooding along Little Pipestone Creek, significant adjustments to the profile baseline needed to be made. The main channel, shown in orange in Figure 10, has very limited capacity and is perched above the left overbank. The majority of flood flows therefore spill into the left overbank. To model the flood hydraulics more accurately, the profile baseline was adjusted to follow the primary flood flow path through the overbank as shown in blue in Figure 10. The floodplain is manually mapped as documentation in Section 7.3.

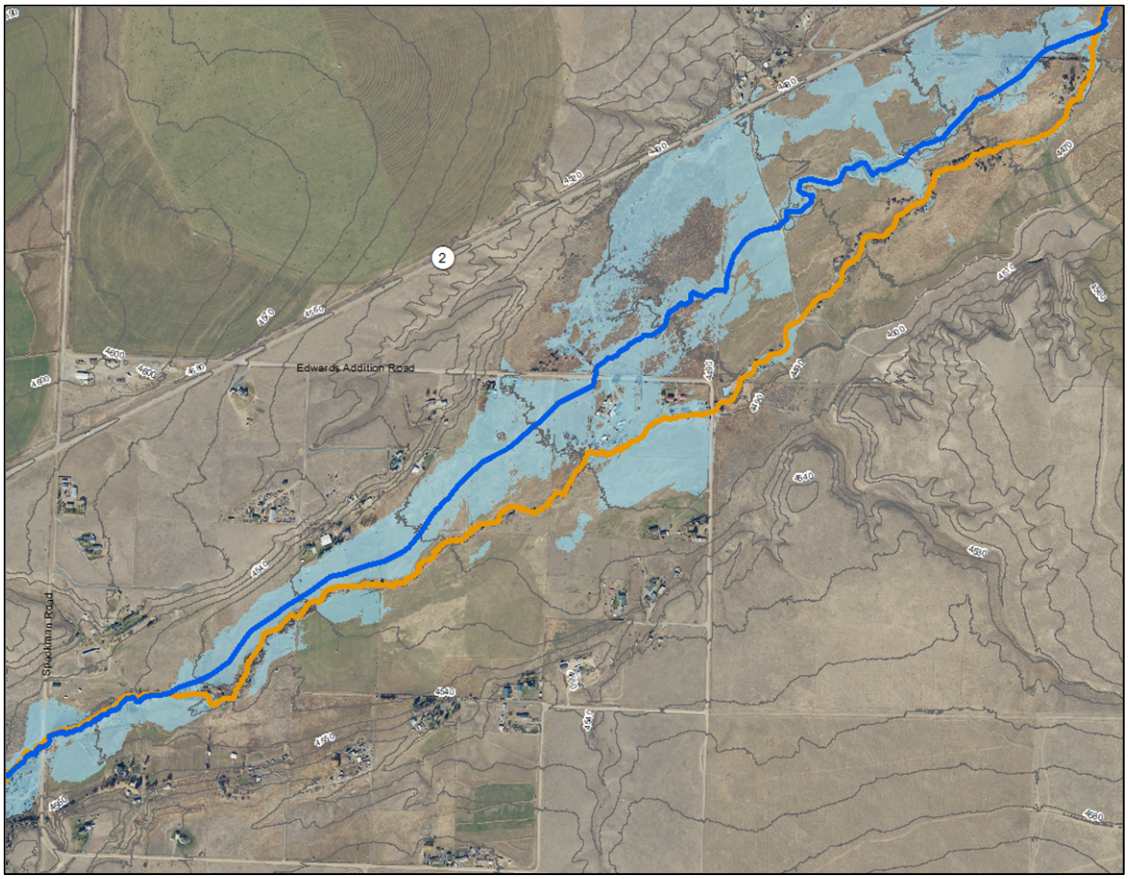


Figure 10: Little Pipestone Creek Profile Baseline Change

There are 15 surveyed structures located in the perched main channel (orange in Figure 10) along this stretch of Little Pipestone Creek. The most downstream structure B27 was not modeled because the boundary is controlled by Big Pipestone Creek. Structure C41a was not modeled because this 12 inch culvert has negligible effect on water surface elevations. Thirteen other structures were not modeled because they are located along the ineffective flow area of the perched channel shown in orange.

5.11 Whitetail Creek

The Whitetail Creek 2D model was developed to simulate the flow split which occurs at the Highway 2 crossing near Whitehall, MT. The model begins at Station 114+92, just north of the Highway 2 crossing and extends south and east to the confluence with the Jefferson River (Figure 11). The 100-year event has a total of 2030-cfs; 1131-cfs passes through the main channel while 899-cfs flows east. Of the 899-cfs in the North Split 407-cfs overtops the highway and railroad. The remaining 492-cfs flows through the culvert under the highway. This flow runs east along the railroad and highway before joining the Jefferson River.

Figure 11: Monitoring Lines for Whitetail Creek

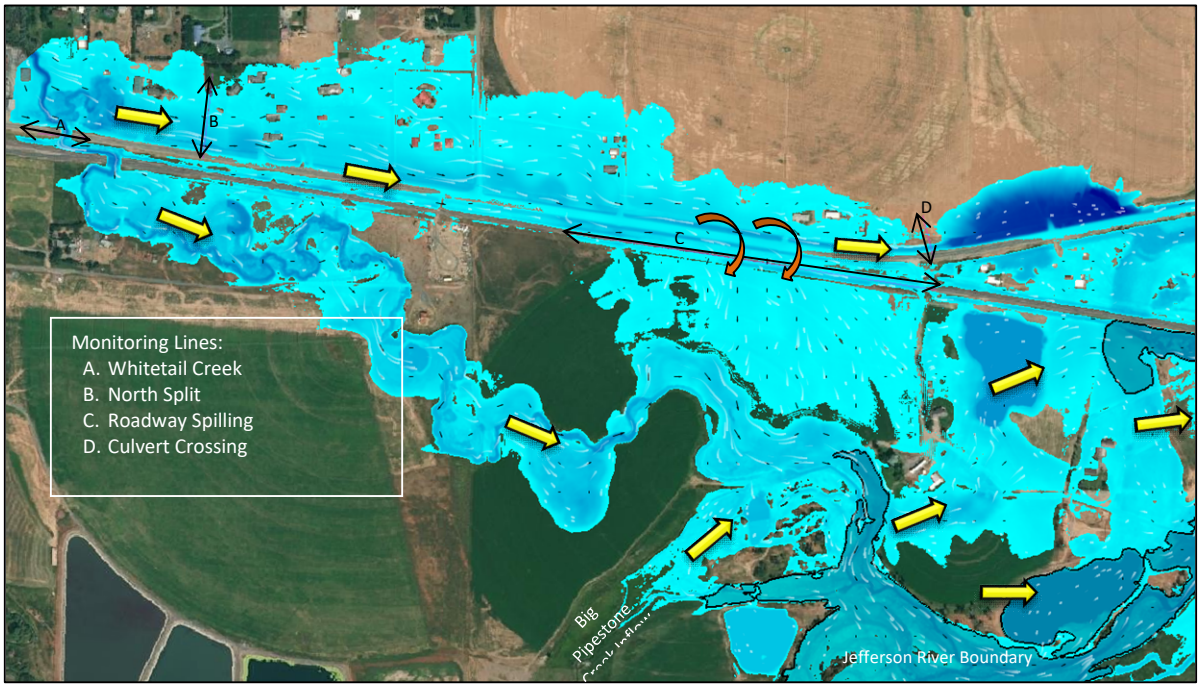


Figure 12 shows the bridge crossing at Sta. 35094 and the roadway embankment that skews across and down the valley. A single water surface elevation is assumed for modeling the area upstream of the bridge, which is controlled by the roadway overtopping flow. However, a portion of the roadway overtopping flow bypasses around a few cross sections downstream of the bridge crossing (Figure 12). For simplicity and to be somewhat conservative in modeling this minor flow split, it is assumed that all the flow passes through the bridge and through all of these downstream cross sections. Ineffective flow limits at the downstream bridge cross sections are set assuming all flows pass through the bridge.

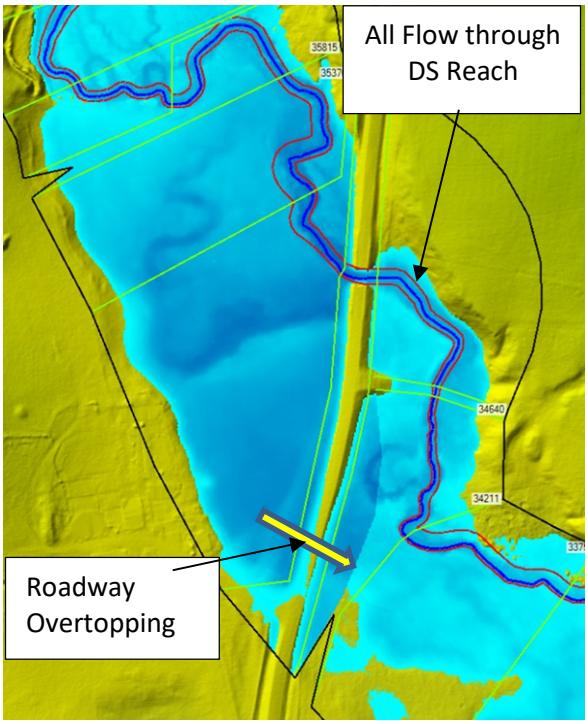


Figure 12: Sta 35094 Floodplain Hydraulics

The upstream study limits of Whitetail Creek were extended beyond the confluence with Little Whitetail Creek. This allowed for more accurate floodplain boundary mapping in the transition area between the two streams. The backwater from Whitetail Creek into Little Whitetail Creek is shown in Figure 13.

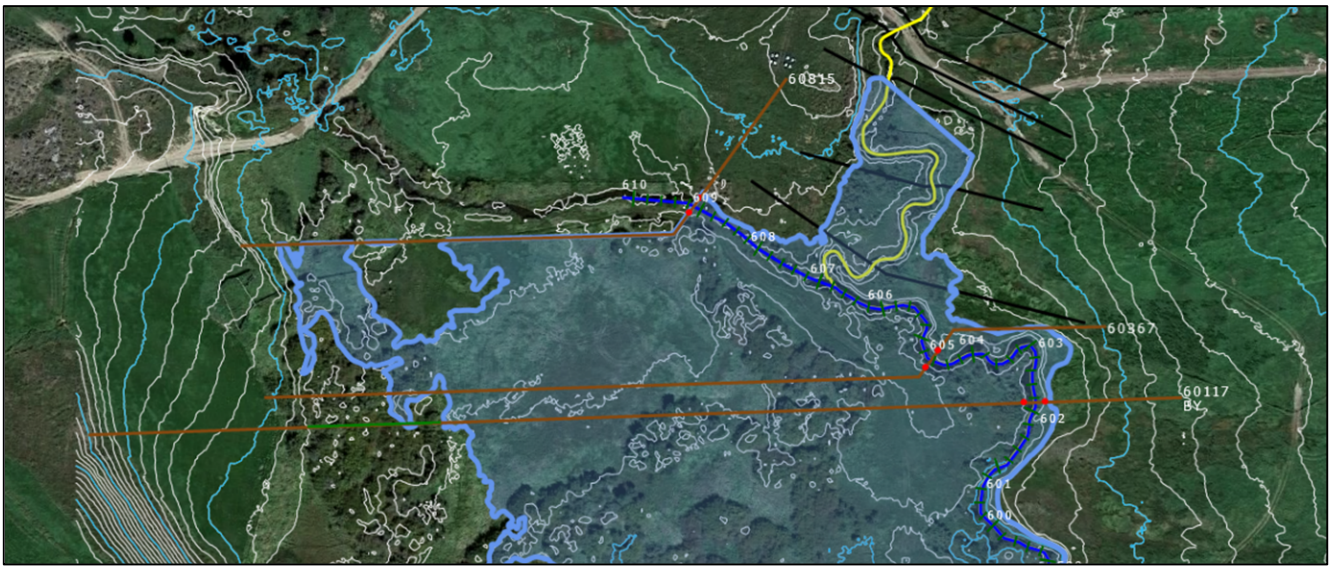


Figure 13: Whitetail and Little Whitetail Floodplain Boundary Transition

5.12 LITTLE WHITETAIL CREEK

The culvert crossing at station 35+17 and lateral weir at station 47+17 are modeled in conjunction. Water begins to spill the private road at cross section 45+13 at the 10-year event. Flows spilling the road enter Little Whitetail Creek again at cross section 35+01. The area between the lateral weir and the downstream cross section, shown in Figure 14, is manually mapped as discussed in Section 7.3.

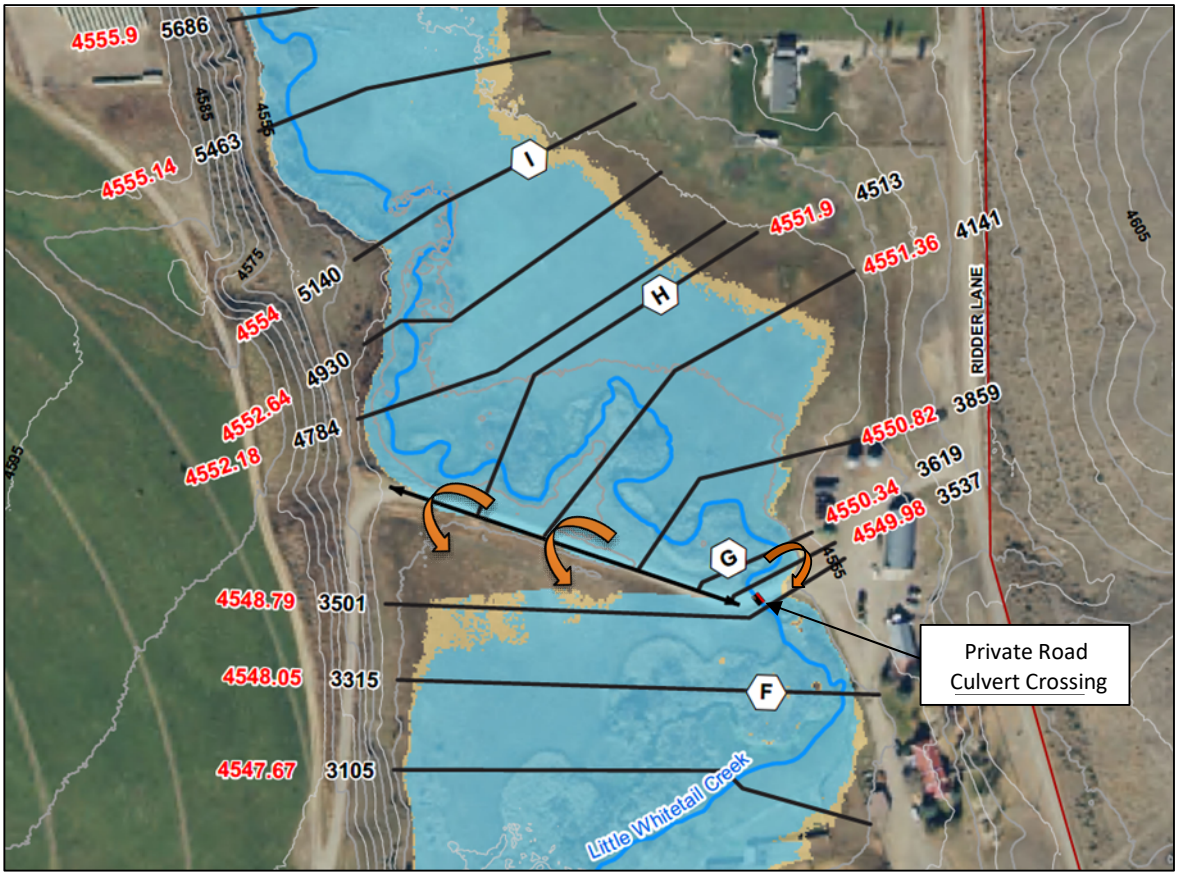


Figure 14**: Culvert Crossing and Lateral Weir**

5.13 PAPPAS CREEK

A Multiple Opening Analysis modeling approach was implemented to describe how flood flows move through the triple-culvert system at the Delmoe Lake Road crossing. The effectiveness of this approach depends on the consistency of flow characteristics between the multiple culvert openings as well as proper identification of stagnation points (specified stationing points of conveyance into each opening). The Multiple Opening Analysis appears to be appropriate at this location since the water surface elevations and flow velocities are similar between the three openings. The stagnation points overlap, which enables GeoHECRAS to iteratively compute the appropriate stationing for conveyance into each culvert.

5.14 Model Calibration

There is minimal information available for direct calibration of the hydraulic models and Montana Department of Transportation (MDT) personnel familiar with the area were unable to offer much information.

5.15 Floodways

A floodway was computed along select "Enhanced with Floodway" reaches of both Big Pipestone Creek and Whitetail Creek. The Big Pipestone reach was computed between MT Highway 2 and directly upstream of the Whitetail Creek confluence (XS 41183 to XS 0). Following FEMA guidance, the 100-year Kountz Road flow split discharge (120 cfs) was added to the main Big Pipestone Reach flow downstream of the split. The water surface elevations along Big Pipestone, with and without the additional flow, were compared to see if they differed by more than 0.5 ft. Adding the Kountz Road flow split discharge back into the main Big Pipestone Reach flow did not increase the water surface elevation by more than 0.1 ft. at any cross section. A floodway is therefore not computed or modeled for the Kountz Road flow split reach.

The floodway boundary for each stream was delineated first by using the HEC-RAS automated methods for equal conveyance, method 5, and then manually adjusted, method 1, in accordance with FEMA standards. Floodway stations are calculated using a maximum allowable surcharge that is determined by the governing criteria of the specific study area. Federal regulations specify a maximum allowable surcharge of 1.0 ft., but State requirements take precedence if they are more stringent than the federal regulation. The floodway analyses was therefore performed using the maximum allowable surcharge of 0.5 ft. as defined by Montana requirements.

The floodways were computed from the furthest downstream cross section, with calculations proceeding upstream, ensuring practical transitions between cross sections.

The Big Pipestone channel is deep and incised between XS 21275 and XS 28102. There is no overbank flow in this area for the 100-year flood, so the floodway is very narrow and either at, or close to, the channel bank stations. The floodway along Whitetail Creek was computed between Interstate-90 and the start of the 2D regulatory model (cross sections 17036 and 11491.77). Similar to the Big Pipestone floodway analysis, the Whitetail Creek floodway water surface elevations were reviewed for noticeable changes greater than 0.5 ft.

The results of the floodway analyses are summarized in Tables 01 and 02 of the Floodway Data Tables presented in Appendix D.

5.16 QUALITY REVIEW

DOWL has developed an internal QA/QC process for review of the Hydraulic Data and Floodplain Mapping for floodplain studies. This includes detailed checklists, an independent review by another water resources engineer, as well as review by a senior engineer. The details of this review are provided in Appendix D.

6.0 RESERVOIR MAPPING

The Zone A boundaries for Delmoe Lake and Whitetail Reservoir were created by determining a 100-year water surface elevation (NAVD88) for the peak discharge over the emergency spillway crest. The recommended flow values are documented in Section 4 and the Jefferson County Hydrologic Analysis Report (Pioneer) is provided in Appendix A. LiDAR data was used to map the boundary at the 100-year water surface elevation.

6.1 DELMOE LAKE

Delmoe Lake Dam is located 25 miles northwest of Whitehall, Montana and is owned by the Pipestone Water Users Association. It is used for irrigation, stock watering, and recreation. The Pipestone Water Users Association has authority and responsibility for safety, operation, and general maintenance. Major repairs and maintenance are coordinated with the Dam Safety Program of DNRC. John Kountz is the president and can be contacted at (406) 287-3849.

Delmoe Lake Dam is classified as a high hazard dam. An assigned dam tender is on sight during the irrigation season, approximately April 1 to September 15. Duties include manually adjusting the gates and valves and performing general maintenance. Maintenance procedures are documented in *Maintenance Procedures – Delmoe Lake Dam (1995),* Appendix A. During the off season, the nearest operating personal are located in Whitehall, 25 miles away. In anticipation of heavy rainfall runoff, the dam tender will open the outlet to maximum capacity. If significant outflow from the emergency spillway is expected, a warning will be provided to downstream residents in accordance with the established Emergency Action Plan.

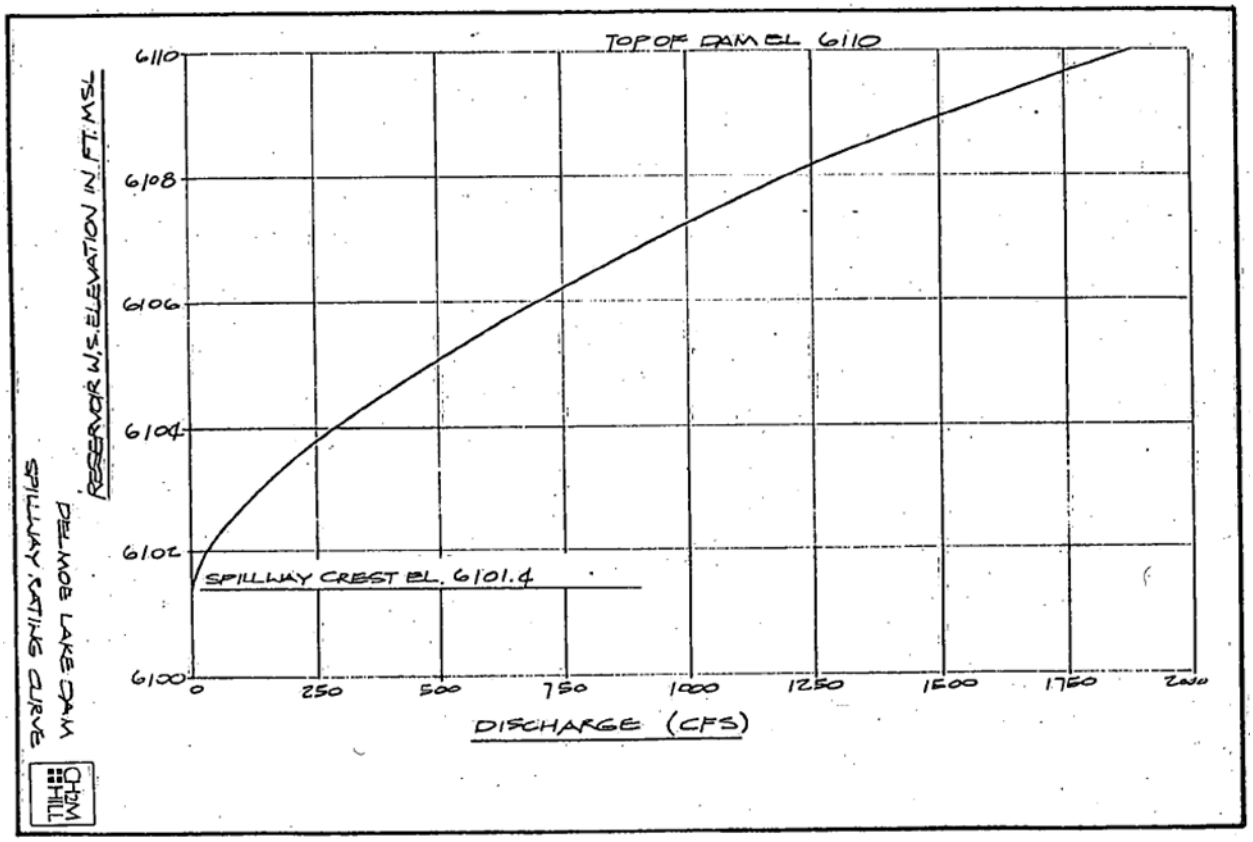
Delmoe Lake Dam is an earthen embankment constructed in 1914 of hydraulic fill with an unreinforced concrete core. The reservoir has a storage capacity of 6,585 acre-feet at the spillway crest and inundates 310 acres. The outlet structure consists of two 24-in diameter steel pipes encased in unreinforced concrete, controlled by manually operated gate valves. At the dam crest elevation, the outlet has an estimated capacity of 150 cfs. The emergency spillway is an uncontrolled, unlined trapezoidal earthen spillway with a crest elevation of 6101.4 ft, and a capacity of 1,900 cfs at the dam crest elevation 6110 ft. The emergency spillway rating curve on Page 8 of the *Delmoe Lake Standing Operating Procedures (1995)* and the peak flow from the hydrologic report, Appendix A, were used to determine the water surface elevation at each flood recurrence interval. Water Surface Elevations for each recurrence interval are shown in Table 16 and the spillway rating curve is shown in Figure 15.

Table 16: Delmoe Lake Water Surface Elevations

Delmoe Lake		
Profile	**Discharge (CFS)**	**Reservoir Water Surface Elevation NAVD88 (ft)**
10% AC	174	6103.3
4% AC	241	6103.7
2% AC	293	6104.1
1% AC	352	6104.3
0.2% AC	503	6105.0
1%+ AC	612	6106.8

*Values were read off existing rating curve

Figure 15: Delmoe Lake Emergency Spillway Rating Curve



6.2 WHITETAIL RESERVOIR

Whitetail Reservoir is located 16 miles northwest of Whitehall Montana and is owned by the Whitetail Water Users Association. It is used for Irrigation, recreation, sediment collection, and flood protection. Whitetail Dam is located on Forest Service property through a special use permit. The dam is classified as Moderate Hazard and the Forest Service inspects the dam every three years. Releases from the reservoir

are typically made between June and September, although limited access due to poor road conditions has occasionally delayed operations until July. There is no formal operating plan or maintenance plan.

The outlet of Whitetail Dam consists of a manually operated control gate, 27-inch reinforced concrete pipe (RCP), a tunnel, and 30-inch RCP. Water enters the 27-inch RCP and then flows through the tunnel to the 30-inch RCP. A diagram of the outlet works is included on page 48 of the inspection report. The reservoir accesses the outlet works when the water surface reaches elevation 7240.0 NGVD29. The outlet works capacity is limited by that of the outlet pipe, which is 68 cfs at the spillway elevation, 7249.0 NGVD29, and 81 cfs at the dam crest elevation, 7256.0 NGVD29.

Whitetail Dam is an earthen embankment constructed in 1921 of hydraulic fill and an unreinforced concrete core. The reservoir has a storage capacity of 4,900 acre-feet at the spillway crest elevation, inundates 900 acres; and has a maximum capacity of 21,400 acre-feet at the dam crest elevation. The spillway is constructed in a granite ledge approximately 130 ft north of the left dam abutment and is controlled by a concrete trapezoidal weir with a crest length of 20ft and 2:1 side slopes. A hydraulic rating relationship for the spillway was developed using HEC-2 and is described in the *National Dam Safety Program Inspection Report for Whitetail Dam Appendix D Engineering Data- Exhibit D3*, in Appendix A. The spillway has a capacity of 1,220 cfs at the dam crest elevation, however Whitetail Dam spillway is not capable of passing flows this large without causing significant erosion. The rating information from HEC-2 and peak flow from the hydrologic report were used to determine the 100-year water surface elevation. Water surface elevations for each recurrence interval are shown in Table 17 and the spillway rating curve is shown in Figure 16.

Table 17: Whitetail Reservoir Water Surface Elevations

Whitetail Reservoir			
Profile	**Discharge (CFS)**	**Reservoir Water Surface Elevation (ft)**	
		NGVD29	**NAVD88**
10% AC	149	7251	7255.4
4% AC	208	7251.6	7256.0
2% AC	255	7252	7256.4
1% AC	308	7252.3	7256.7
0.2% AC	444	7253.1	7257.5
1%+ AC	536	7253.6	7258.0

*NOAA VERTCON used to create NAVD88 elevations from NGVD29.

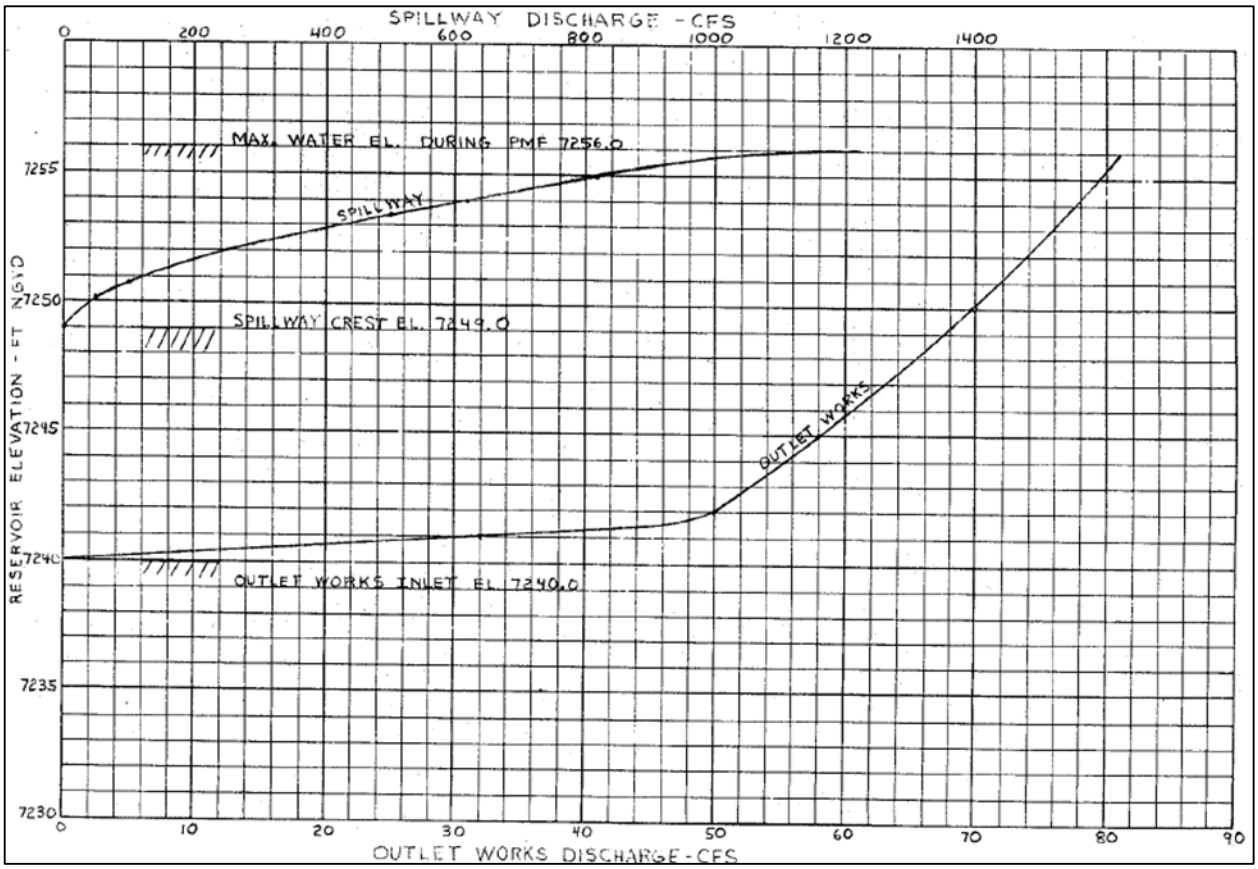


Figure 16: Discharge Rating Curves Whitetail Dam

7.0 FLOODPLAIN MAPPING

The initial flood boundary outputs from the Hydraulic Modeling task must be refined to realistically portray actual flooding extents. DOWL has implemented best practices for floodplain mapping to improve the accuracy and representation of flood boundaries, which requires extra attention to detail in some areas as described below.

The Floodplain Mapping task was completed using ESRI ArcMap 10.5.1, AutoCAD 2016, and RAS Plot v3. Hydraulic model outputs take the form of depth grids and water surface elevation rasters. Depth and water surface elevation rasters were exported from HEC-RAS 5.0.7 as initial hydraulic model outputs for the Floodplain Mapping task. Flood risk boundaries were modified using spatial processes including global refinements, manual mapping, and final boundary smoothing. Modifications to the boundary were made in accordance with FEMA mapping standards and *MT CTP Best Practices (2018).*

7.1 FLOODWAY MAPPING

Big Pipestone Creek and Whitetail Creek both have floodway zones. Points representing the appropriate encroachment stations were used to map each floodway. A smooth boundary was mapped between model cross sections while taking care to fully encompass the profile baseline throughout the floodway extents. The final delineated floodway width was compared to floodway widths from the approved hydraulic model and verified to be mapped within ±5%. These results are shown in Appendix H.

7.2 GLOBAL REFINEMENTS

Global refinements are accomplished using a variety of geoprocessing tools in ArcMap. These processes are used to classify and fill/remove voids within the boundary and to remove fragmented polygons outside the floodplain boundary. A void, or "island," is a gap in the raw hydraulic model output where the interpolated water surface elevation is lower than the terrain surface. All voids less than 625 sq. ft. (25 ft. x 25 ft.) were deemed insignificant and automatically filled. Remaining voids were reviewed individually by comparing the average terrain surface elevation to the 100-year water surface elevation. Voids with insurable structures were also reviewed using terrain contouring, Lowest Adjacent Grade (LAG) data, and the FIS water surface elevation profiles before accepting additions to the floodplain boundary. A summary of reviewed structures is included in Appendix H.

7.3 MANUAL MAPPING

Manual mapping involves applying engineering judgment for refinements to hydraulic mapping limitations by reviewing the model details and associated terrain surfaces—some of these limitations

include diverging water surfaces, backwater adjustments, roadway overtopping, and cascading water surfaces.

Diverging water surfaces can occur where there is a split flow but is not significant enough to be incorporated into the model. These splits represent small flows or are modeled as ineffective. When the main/modeled channel water surface elevation drops faster than the water surface of the split flow, split flow flood hazards can be missed in the mapping. Section 5.10 discusses the perched channel of Little Pipestone Creek; since the modeled water surface elevation drops faster than the terrain surface along the perched main channel, the perched channel is not captured in the initial mapping. Though the low-flow main channel has a small capacity, it is deemed a flood hazard and is mapped manually. Figure 17 shows the manual mapping along the perched main channel (orange polyline), the new hydraulic profile (blue polyline), the raw hydraulic model boundary (white outline), and the final mapping boundaries (blue polygon: 100-year & tan polygon: 500-year).

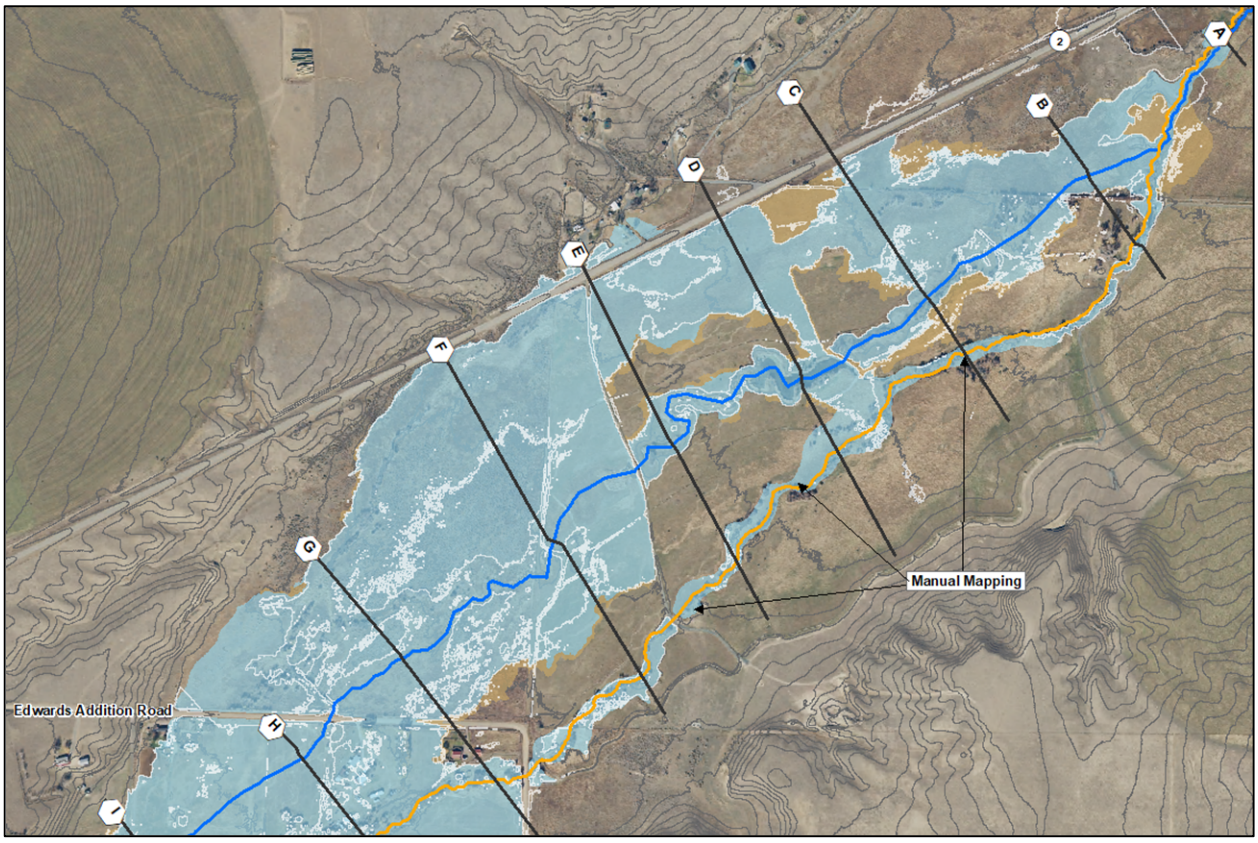


Figure 17: Little Pipestone Creek Disconnected Flow - Manual Mapping Correction

The hydraulic modeling outputs can underpredict or overpredict the water surface boundary for backwater zones. Backwater adjustments are made by replacing the sloped water surface with a boundary that represents a single water surface. Areas influenced by backwater and their associated backwater elevations are indicated in Appendix H.

Roadway crossings which exhibit minor overtopping or a large water surface elevation differential between the upstream and downstream cross sections are often not accurately mapped in the raw hydraulic outputs. Since roadways may need to be used as emergency routes, it is important to accurately map roadway overtopping.

The raw hydraulic outputs also do not typically accurately map cascading flows. Section 5.11 shows a section of Little Whitetail Creek where this mapping

Figure 18: Manual Mapping of Lateral Weir Overtopping

limitation is apparent. Using the overtopping stationing along the lateral weir and the ground elevation contours, this flood risk was manually mapped. Figure 18 illustrates the raw hydraulic model output (white outline) as compared to the final mapping boundaries (blue polygon: 100-year & tan polygon: 500-year).

7.4 Non-Levee Features Modeling and Mapping

It has been standard practice in the state of Montana to extend cross sections through non-levee features in the Hydraulic Modeling Task with the intent to map the backside in the Floodplain Mapping Task. A draft memo stating the suggested approaches for modeling and mapping was submitted in May 2021 and is included in Appendix A. For this study the first approach was used which states:

> *"First Approach – Simply extend the BFEs from the stream side to the landward side. This approach is appropriate where the flow areas on the landside of the levee would not be significant and would not significantly reduce the BFE. Examples of this approach include when the area behind the embankment is very small and/or primarily ineffective flow area, or a populated area where the ground is not significantly lower than the with levee BFE and you have a lot of obstructions to the flow. Engineering judgment should be used to determine when this approach is appropriate." (Memo Page 3)*

It is also stated that cross sections are not truncated to high points of non-levee features.

> *"It is also recommended that they not truncate the cross section at the non-levee feature in either the model or the floodplain mapping files." (Memo Page 4)*

7.5 Other Mapping Considerations

7.5.1 1D/2D Connections

Whitetail Creek and Fish Creek had 1D/2D connections and the 2D base flood elevation (BFE) contours needed to be adjusted for a smooth transition between the 1D cross section water surface elevations and the 2D BFEs. Figure 19 shows the original 2D BFEs (red polyline) and the refined BFE (dark blue polyline) which smoothly transitions to the water surface elevation at the 1D cross section labelled "O".

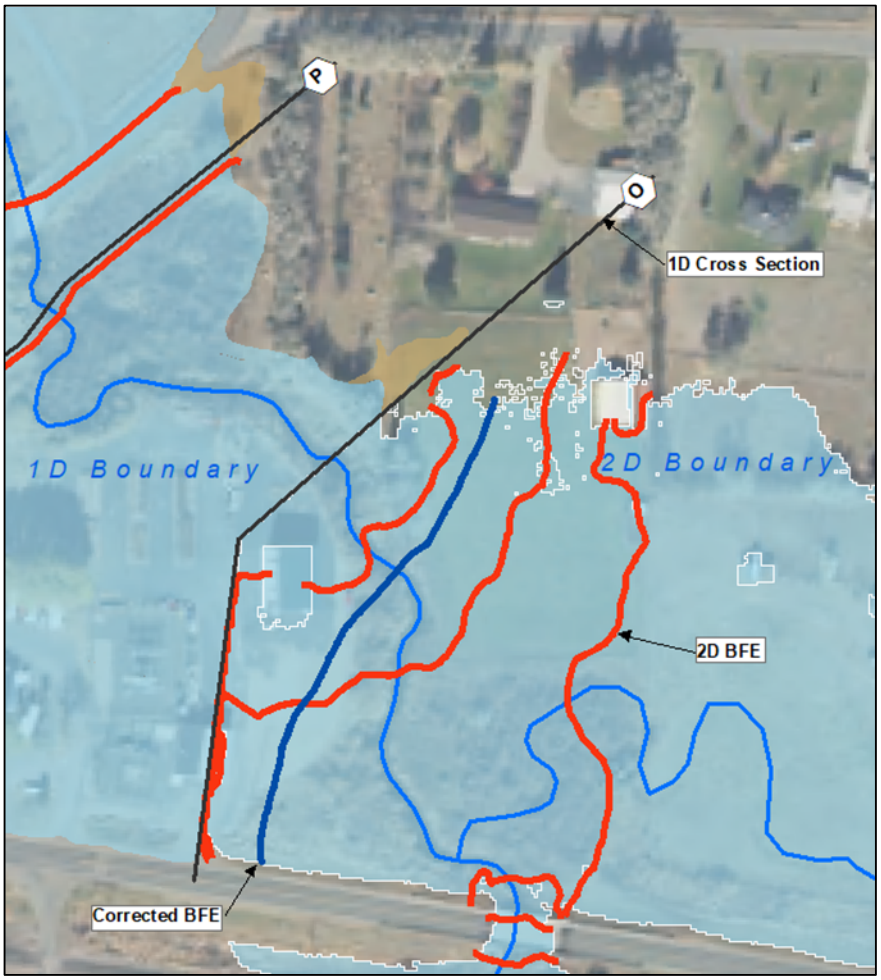


Figure 19: 1D/2D Connection BFE Correction

7.5.2 Severity Mapping

The floodplain of Fish Creek, from the confluence of the Jefferson River to station 491+55.34, is primarily shallow flooding over an alluvial fan. Supplemental work maps show this using a classified depth raster provided in Appendix H. The average depth across any point in the floodplain is less than one foot, which could be classified as Zone X.

Rather than terminate the Zone AE floodplain at station 491+55.34, DOWL proposes to map the "Major Flow Paths" as Zone AE and the shallow overbanks as Zone X. FEMA Guidance, *Flood Depth and Analysis Rasters (December 2020),* Section 8 describes the methods for using a Flood Severity Raster. The flood severity raster represents a continuous surface of multiplied depth and velocity values from the 2D hydraulic model output grids (D*V, in units of ft^2/sec). These values are then classified into five categories—Table 18 shows the categories and their respective D*V ranges.

Table 18: Flood Depth and Analysis Flood Severity Ranges

Flood Severity Category	Depth * Velocity Range (ft^2/sec)
Low	<2.2
Medium	2.2-5.4
High	5.4-16.1
Very High	16.1-26.9
Extreme	>26.9

Mapping the Zone AE for Fish Creek was completed using a combination of the classified Flood Severity Raster and the topography. A boundary encompassing identifiable, major flow paths exhibiting "Medium" or higher flood severity classification were mapped as Zone AE floodplain. Minor and/or disconnected "Medium" or lower flood severity classifications were mapped as Zone X. The final boundaries as compared to the severity classification are shown in supplemental work maps provided in Appendix H.

7.6 Floodplain Boundary Standards

Floodplain Boundary Audits were performed in accordance with FEMA Guidance, *Floodplain Boundary Standards (FBS) (November 2019) Section 4.1.* These audits quantify the reliability of the floodplain boundary by computing the difference between the flood elevation and the terrain surface. The Jefferson River Tributaries are in Risk Class "C" and the results of this audit are provided in Appendix H. Required TIN surface and comparison points have also been included.

7.7 Kountz Road Mapping

Along the Kountz Road split of Big Pipestone Creek it appears though Kountz Road is providing protection against the 1% AC flood event. Projecting the water surface through the roadway to a natural ground surface tie in results in multiple small narrow polygons, approximately 15 feet in width. These small polygons are irrelevant at map scale and are typically removed during the Global Refinements or Manual Refinements Phase of floodplain mapping.

8.0 FLOOD INSURANCE STUDY PRODUCTS

The Flood Insurance Study products for this Jefferson Countywide Floodplain Study include Floodway Data Tables and flood profiles. Flood profiles were developed for all streams using RASPLOT Version 3.0. This software extracts the results from the HEC-RAS analysis, creates databases for each modeled creek, and exports the Floodway Data Tables. Floodway Data Tables were developed for the floodway segment of Big Pipestone Creek and Whitetail Creek.

RASPLOT uses information entered on the plot extents and labels to create and export the flood profiles to DXF files. The resulting profiles were reviewed and edited as necessary for better placement of labels and then exported to PDF files.

Profiles for regulatory 2D model reaches are based on ground surface elevations extracted from the LiDAR and water surface elevations extracted from water surface elevation grids at 300-ft intervals. Additional points along the profile are included upstream and downstream of hydraulic structures. Lettering is assigned to these additional points for reference.

9.0 REFERENCES

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Appendix A: Technical Reports

Appendix B: Working Maps

Appendix C: Flood Profiles

Appendix D: Floodway Data Tables

Appendix E: Model Review

Appendix F: HEC-RAS Model Documentation

Appendix G: HEC-RAS Model Outputs

Appendix H: Mapping Documentation